GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: June 29, 1978

Project Title: Investigation of MARCOR Landing System

Project No: A-2143

Project Director: Dr. R. N. Trebits

Sponsor: Naval Supply Center; Oakland, Calif. 94625

Agreement Period: From 5/2/78 Until ~~1/31/79~~ 31 Jul 79

Type Agreement: Contract No. N00228-78-C-2215

Amount: $29,984

Reports Required: Monthly Progress Reports; Final Report.

Sponsor Contact Person (s):

Technical Matters

Naval Electronic Systems Engineering Center
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Vallejo, Calif. 94592

Contractual Matters
(thru OCA)

Office of Naval Research
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Atlanta, Georgia 30332

Defense Priority Rating: DO-S1 under DMS Reg. 1.

Assigned to: Radar Instrumentation Laboratory (School/Laboratory)

COPIES TO:

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Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
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Other

CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 11/20/80

Project Title: Investigation of MARCOR Landing System

Project No: A-2143

Project Director: Dr. R.N. Trebits

Sponsor: Naval Supply Center, Oakland, Calif. 94625

Effective Termination Date: 7/31/79 (R&D Perf. Period)

~~Clearance of Accounting Charges:~~ 7/28/80 (Reporting Period)

Grant/Contract Closeout Actions Remaining:

- X Final Invoice and Closing Documents
- _ Final Fiscal Report
- _ Final Report of Inventions *
- _ Govt. Property Inventory & Related Certificate *
- _ Classified Material Certificate *
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CA-4 (1/79)

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

25 September 1978

Naval Electronic Systems Engineering Center
Code 510
Vallejo, California 94592

Subject: Monthly Contract Technical Status Report No. 1-4, "Investigation of MARCOR Landing System," Contract No. N00228-78-C-2215 (Georgia Tech Project A2143) Covering the Period From 2 May to 31 August 1978

Gentlemen:

This status report summarizes activities performed under the subject contract for the period 2 May to 31 August 1978.

Technical Progress

On 9 and 10 May Dr. Trebits and Dr. Licata attended a meeting of the MATCALS executive board. The objective of this meeting, called by NAVELEX, was to evaluate the status of the AN/TPN-22 radar development program. John Gallagher of NESEA summarized the testing of the radar and identified a problem area in the pitch and bank commands to the aircraft necessary for automatic landing. Lon Sander of ITT presented an overview and a status of the modifications to the TPN-22. Roger Noury of Bell Aerospace described the controller system which takes output from the radar and generates pitch and bank commands that are sent to the aircraft. Ron Hess of McDonald-Douglas Astronautics described the SPN-42 radar system used by the Navy to provide automatic landing on aircraft carriers.

The outcome of this meeting was that a considerable effort would be required to modify the TPN-22 radar in order that it perform an automatic landing function. Some doubt was felt of this system's ever being capable of this function at all. Another meeting was scheduled for June to present ideas for assisting the TPN-22 problem areas. This meeting was never held, and no subsequent meetings have been scheduled through August 1978.

Georgia Tech anticipated several task assignments as a result of the May meeting of the MATCALS executive board. No assignments have been made as of this date.

At this point vacation schedules at Georgia Tech have prevented any full scale efforts on the MATCALS analysis program. The apparent conflict between the statement of work of the current contract and the issue of the MATCALS executive board to assign specific work tasks has yet to be resolved. Unless otherwise directed, Georgia Tech will now increase the level of effort on this program to respond to the statement of work. Changes to this direction requested by the MATCALS executive board must then carry the approval of the Naval Electronics Systems Engineering Center.

Respectfully Submitted,

Robert N. Trebits
Project Director

RNT/vcy

Approved:

J. D. Echard, Chief
Radar Applications Division

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

December 18, 1978

Naval Electronic Systems Engineering Center
Code 510 - Attn: Mr. G. Stovall
Vallejo, California 94592

Subject: Monthly Contract Technical Status Report Nos. 5-7, "Investigation of MARCOR Landing System", Contract No. N00228-78-C-2215 (Georgia Tech Project A-2143) Covering the Period from September 1 to November 30, 1978.

Gentlemen:

This status report summarizes activities performed under the subject contract for the period September 1 to November 30, 1978. By NAVELEX request all work associated with the existent statement of work had been discontinued until late October. Thus, this status report includes the overall time period including that for which redirected technical efforts have been expended.

Technical Progress

Georgia Tech was notified by telephone on October 31, 1978 of a MATCALS program review to be held on November 7 and 8 at NAVELEX. The purpose of this meeting was to review the efforts ITTG has made for tracking improvement of the AN/TPN-22 radar system and to assign specific tasks to several support contractors, including GIT/EES. The major radar modifications are to be in areas of (1) signal compression and spectral filtering, (2) gated AGC, and (3) tracking functions.

Georgia Tech was requested to provide inputs for a statement of work for McDonnell Aircraft, to perform a literature search on Mode I landing system information, and to initiate radar system analyses on the AN/TPN-22 with emphasis on tracking errors. In addition, Georgia Tech would provide a revised statement of work reflecting the above enumerated tasks and would also begin work on a radar system tutorial in preparation for another meeting on November 28 and 29.

In response to this first meeting, a tutorial outline was prepared for review at the Van Nuys meeting. Computer programs were modified to permit analyses of the edge track performance process of the AN/TPN-22 radar system. Dr. Trebits and Mr. Appling of GIT/EES attended the MATCALS meeting at Van Nuys and participated in the discussions of ITTG's efforts toward improving the radar's tracking accuracy.

Future Efforts

Action items as a result of the MATCALS meeting at Van Nuys include (1) preparation of a revised statement of work for GIT/EES participation on this program, (2) preparation of a detailed outline for a tutorial with emphasis on the edge track technique employed by the AN/TPN-22 radar system, and (3) input for a statement of work regarding McDonnell Aircraft's involvement in this program. Computer programming and coding for analyzing the various sources of tracking errors will be completed during December. The programs will then be exercised against the various AN/TPN-22 system parameters to bound the individual and aggregate tracking errors.

Respectfully submitted,

Robert N. Trebits
Project Director

Approved:

J. D. Echard
Chief, Radar Applications Division

RNT/dw

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ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

February 1, 1979

Naval Electronic Systems Engineering Center
Code 510
Vallejo, California 94592

Attention: Mr. Greg Stovall

Subject: Monthly Contract Technical Status Report No. 8, "Investigation of MARCOR Landing System", Contract No. N00228-78-C-2215 (Georgia Tech Project A-2143), Covering the Period 1 through 31 December 1978

Gentlemen:

This status report summarizes activities performed under the subject contract for the period 1 through 31 December 1978.

Technical Efforts

Several action items were generated at the MATCALS meeting held in November at ITTG, and these are described here:

1. A formal outline was prepared and mailed to NAVELEX which described a presentation entitled "A Tutorial Presentation of the AN/TPN-22 as a Generic Tracking Radar System."

2. A list of potential tasks for McDonnell Aircraft's participation in the MATCALS program was prepared and mailed to NAVELEX.

3. A revised statement of work was prepared and mailed to NAVALEX. This revised SOW describes the tasks to be performed by Georgia Tech on the MATCALS program under the current contract.

4. A list was prepared which describes several key task areas in which Georgia Tech can be of significant benefit within the context of the MATCALS concept.

Work also continued during December on a computer analysis of AN/TPN-22 tracking errors. Each source of tracking error has been analytically modeled and encoded in standard FORTRAN IV programming language. By month's end, the computer programming tasks were essentially complete and ready for exercising on Georgia Tech's CYBER 74 computer. Initial running of the main program was undertaken for debugging purposes and to identify data trends.

Future Efforts

The computer tracking error programs will be extensively exercised for the AN/TPN-22 system parameters and aircraft target characteristics. The tutorial presentation will be prepared for presentation at a MATCALS meeting tentatively scheduled for early February. A request for additional funding plus a time extension to the contract period will be made in January to account for the increased scope of work reflected in the revised statement of work.

Respectfully submitted,

Robert N. Trebits
Project Director

Approved:

J. D. Echard
Chief, Radar Applications Division

RNT/dw

A-2143

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

February 21, 1979

Naval Electronic Systems Engineering Center
Code 510
Vallejo, California 94592

Attention: Mr. Greg Stovall

Subject: Monthly Contract Technical Status Report No. 9, "Investigation of MARCOR Landing System", Contract No. N00228-78-C-2215 (Georgia Tech Project A-2143), covering the period 1 through 31 January 1979.

Gentlemen:

This status report summarizes activities performed under the subject contract for the period 1 through 31 January 1979.

Technical Efforts

The computer program analysis of the TPN-22 radar system tracking errors continued throughout this month. This program calculates the radar tracking errors attributable to individual contributors, such as signal-to-noise ratio, servo response, glint, scintillation, system granularity, etc. The target is modeled as a two scatterer entity, whose components depend the radar antenna scan direction. The model is not intended to be constructed as a two scatter model of the entire aircraft. This computer program has been exercised for various ranges of values of (1) scatterer separation, (2) scatterer return power ratio, (3) antenna pattern threshold, and (4) track filter (servo) bandwidth. Some of the more significant results of this computer investigation have been documented for inclusion in a briefing to be presented to NAVELEX in February.

Work has also progressed on a tutorial presentation regarding tracking radar system concepts in general and the TPN-22 edge track technique in particular. This effort will be stratified such that it may be delivered at a technical level appropriate to the audience. The oral presentation to NAVELEX in February will represent one manifestation of this tutorial, namely a technically oriented one stressing analytical techniques and observations.

Future Efforts

Georgia Tech will participate in a MATCALS technical meeting to be held at NAVELEX on 6 and 7 February 1979. At that time, the tutorial presentation will be made at a technical level, stressing the identified limiting tracking parameters of the TPN-22 radar system and the possible measures which could improve radar tracking performance. Refinement of the tracking program will continue with the goal of a truly representative description of radar tracking potential.

Respectfully submitted,

Robert N. Trebits
Project Director

Approved:

J. D. Echard, Chief
Radar Applications Division

RNT/dw

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

2 April 1979

Naval Electronic Systems Engineering Center
Code 510
Vallejo, California 94592

Attention: Mr. Greg Stovall

Subject: Monthly Contract Technical Status Report No. 10, "Investigation of MARCOR Landing System," Contract No. N00228-78-C-2215 (Georgia Tech Project A-2143), covering the period 1 through 28 Feburary 1979.

Gentlemen:

This status report summarizes activities performed under the subject contract for the period 1 through 28 February 1979.

Technical Efforts

R. N. Trebits, E. S. Sjoberg and B. C. Appling attended a meeting at NAVELEX on 6 and 7 February to discuss the development status of the AN/TPN-22 radar system and other MATCALS components. Attendance was essentially limited to the various Navy organizations involved plus those of us from Georgia Tech and Auburn University. Georgia Tech's participation in the first day's session involved discussions with personnel at Patuxent River concerning their flight test program of F-4 aircraft and the AN/TPN-22 radar system. Strip chart data showing aircraft position information were shown and analyzed with respect to recently made software modifications to the radar tracking filters. Preliminary observations of these data indicate acceptable aircraft rod-end loading characteristics. However, the spatial deviations of the aircraft from the glide slope were occasionly very large, even though the ride was "smooth". Georgia Tech expressed a desire to interface directly with the Patuxent River testing as participants and analysts, in order to be more closely associated with the AN/TPN-22 radar system performance evaluation process.

On the second day of this meeting, Georgia Tech and Auburn made tutorial presentations, on the AN/TPN-22 tracking analysis and closed loop characteristics respectively. Georgia Tech's presentation was designed to (1) define the AN/TPN-22 as a generic radar tracking system, in historical perspective, (2) calculate individual and aggregate tracking errors for identified phenomena, and (3) identify areas of necessary radar system improvement, along with potential mechanisms for achieving this goal.

Improvement and refinement of the computer model for predicting tracking performance is continuing. Areas for continued study include refining the probability of edge-track calculation and the method for combining the normal and edge track statistics. An additional source of tracking error not included previously which will be added in the future is the induced scintillation and glint due to frequency scanning in the elevation plane. The results of the computer analysis to date agree reasonably well with the measured radar performance. It is hoped that the final results of our computer analysis will indicate which areas of the radar system limit the tracking performance and thus indicate where additional effort is required.

Respectfully submitted,

Eric S. Sjoberg
Associate Project Director

Approved:

J. D. Echard, Chief
Radar Applications Division

ESS/dw

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

April 26, 1979

Naval Electronic Systems Engineering Center
Code 510
Vallejo, California 94592

Attention: Mr. Greg Stovall

Subject: Monthly Contract Technical Status Report No. 11, "Investigation of MARCOR Landing System," Contract No. N00228-78-C-2215 (Georgia Tech Project A-2143), covering the period 1 through 31 March 1979.

Gentlemen:

This status report summarizes activities performed under the subject contract for the period 1 through 31 March 1979.

Technical Efforts

A meeting was held during March at the Georgia Tech Research Facility at Cobb County with Drs. Charles Phillips and Scott Starks of the Electrical Engineering School of Auburn University. Attending for the Georgia Tech Engineering Experiment Station were R. N. Trebits, E. S. Sjoberg, and B. C. Appling. The Project Engineer at NAVELEX was not able to attend because of cancelled airplane reservations due to inclement weather in Atlanta.

Dr. Phillip presented to this group that part of the Auburn tutorial which he had been unable to give at the February meeting at NAVELEX. The remainder of the meeting's activities were spent discussing Auburn and Georgia Tech's future technical involvement in the MATCALS program. It was decided that the most efficient and effective procedure will be to generate at joint proposal effort to NAVELEX including both university participants plus Robert Simpson of Flight Transportation Associates, who is currently under contract to Auburn in the area of air traffic control.

Refinement of the AN/TPN-22 tracking error computer model is continuing. Emphasis during this month has been in effects of ground clutter and multipath effects, and in more accurate probability of edge-track formulation.

Future Efforts

The computer model efforts will continue during April as each refinement is incorporated into coding. Tutorial efforts will be also continued, toward a written output. A joint proposal effort will be initiated which addresses areas of future fruitful involvement in the development of the MATCALS system.

Respectfully,

Robert N. Trebits
Project Director

Approved:

Jim D. Echard, Chief
Radar Applications Division

RNT/dw

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

May 21, 1979

Naval Electronic Systems Engineering Center
Code 510
Vallejo, California 94592

Attention: Mr. Greg Stovall

Subject: Monthly Contract Technical Status Report No. 12, "Investigation of MARCOR Landing System", Contract No. N00228-78-C-2215 (Georgia Tech Project A-2143), covering the period 1 through 30 April 1979

Gentlemen:

This status report summarizes activities performed under the subject contract for the period 1 through 30 April 1979.

Technical Efforts

Activities during the month of April centered on refining the computerized error analysis model for the AN/TPN-22 radar system. Six specific areas were addressed and five of these were resolved. Those five included:

1. Exact method for computing the probability of edge track. This is based on the signal strength ratio as defined in our February briefing at NAVALEX.

2. Exact method of mixing the edge track errors and "normal" errors, based on the probability of edge track.

3. Position errors associated with detecting at other than the -12db point if the antenna pattern were included in the program. The largest contributor to this error source is the beam step granularity.

4. The instrumental/granularity error associated with the TPN-22 were reduced by the number of independent position determinations made during the integration time of the servo loop.

5. The computer program was modified to account for the averaging procedure used in the radar to find the target centroid.

The remaining task involves determining the amount of scintillation and glint induced by the frequency scan used to control beam elevation in the AN/TPN-22. All the program modifications required by the first five tasks have been completed and checked.

Future Efforts

One task remains on the error analysis. This task should be completed during June. An additional effort currently being addressed is an automated plotting routine, which will graph the results of the computer error analysis. This has the benefits of yielding easily understandable results faster and more economically than hand plotting. Efforts toward producing the written tutorial are proceeding and should also be complete in June.

Respectfully submitted,

Eric S. Sjoberg
Associate Project Director

Approved:

J. D. Echard, Chief
Radar Applications Division

ESS/dw

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

June 29, 1979

Naval Electronic Systems Engineering
Center
Code 510
Vallejo, California 94592

Attention: Mr. Greg Stovall

Subject: Monthly Contract Technical Status Report No. 13, "Investigation of MARCOR Landing System", Contract No. N00228-78-C-2215 (Georgia Tech Project A-2143), covering the period 1 through 31 May 1979

Gentlemen:

This status report summarizes activities performed under the subject contract for the period 1 through 31 May 1979.

Technical Efforts

The remaining task item in the refinement of the computer error analysis model for the AN/TPN-22 radar tracker concerned the amount of target scintillation and glint resulting from the frequency scanning used to control beam elevation. Inquiries were made through several sources about the radar cross section variation of the F-4 aircraft with small changes in radar frequency, but to date no useful information has been received. Otherwise the model refinement task was complete, inasfar as those items presently designated for incorporating into the model were concerned.

The final technical report effort was initiated during May, incorporating the body and substance of the tracking radar tutorial, as discussed with the project engineer. This report will summarize Georgia Tech's activities on this MATCALS contract, and will include discussions of generic tracking radar concepts, the AN/TPN-22 edge track technique, the error analyses computed, and recommendations for improvement of this radar's tracking performance.

Future Efforts

The work on the final technical report will continue in June. A visit by the project engineer to the Georgia Tech Research Facility at Cobb County is planned for 14 June 1979 to review program results and recommendations, to inspect the EES facility, and to plan follow-on university activities on the MATCALS effort.

Respectfully submitted,

Robert N. Trebits
Project Director

Approved:

J. D. Echard, Chief
Radar Applications Division

RNT/dw

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

August 2, 1979

Naval Electronic Systems Engineering
Center
Code 510
Vallejo, California 94592

Attention: Mr. Greg Stovall

Subject: Monthly Contract Technical Status Report No. 14, "Investigation of MARCOR Landing System," Contract No. N00228-78-C-2215 (Georgia Tech Project A-2143), covering the period 1 through 30 June 1979

Gentlemen:

This status report summarizes activities performed under the subject contract for the period 1 through 30 June 1979.

Work during the month of June centered on the final technical report and planning future technical activities in support of the MATCALS program. It was decided to include the written tutorial on tracking radar, as presented to NAVELEX, Washington, D.C., in February as a part of the final report. Further analysis results and more detailed explanation of the analysis procedure will also be included in the final report.

The Project Engineer visited the Georgia Tech Research Facility at Cobb County during June. Future Georgia Tech involvement with the MATCALS program and Tech's capabilities to support other NAVELEX programs were discussed.

Activities during July will include: finishing the computer modeling effort to incorporate scintillation due to frequency scan and preparation of a proposal to NAVELEX for future university involvement in MATCALS. Work will continue on the final report.

Respectfully submitted,

Eric S. Sjoberg
Associate Project Director

Approved:

J. D. Echard, Chief
Radar Applications Division

Final Technical Report
Georgia Tech Project A–2143
Contract No. N00228–78–C–2215

INVESTIGATION OF MARCOR LANDING SYSTEM

by
R. N. Trebits, E. S. Sjoberg, and B. C. Appling

January 1980

Prepared for
Naval Electronic Systems Engineering Center
Vallejo, California 94592

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia 30332

1980

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

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Radar	Glint	Precision Approach Radar
Tracking Errors	Microwave	Microwave Landing System
Scintillation	Track-While-Scan	Statistical Error Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this program was to investigate and evaluate the tracking concept utilized by the Marine Air Traffic Control and Landing System (MATCALS) precision approach radar. A detailed statistical error analysis of the AN-TPN-22 radar system was undertaken by computer modeling of individual sources of tracking error. The various types of tracking error sources included signal-to-noise ratio, target scintillation and glint, tracking filter lag, ground/

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) sea clutter, multipath interference, and granularity/instrumentation effects. The outputs of this AN/TPM-22 computer tracking model were characterizations of individual elevation and azimuth channel tracking errors as a function of range for various appropriate parameter values. Net elevation and azimuth tracking errors were also calculated by appropriate summation of the individual error contributions.

As part of this tracking error investigation, Georgia Tech participated in AN/TPN-22 contractor reviews, providing an independent technical assessment of proposed radar system modifications. Finally recommendations were provided in areas which had been identified as being more amendable to upgrading of radar tracking performance.

A management oriented, tutorial description of tracking radar system concepts and applicable tracking error sources was prepared and presented. Particular emphasis was placed on the edge track technique employed by tne AN/TPN-22 radar system and those phenomenological and system error sources particularly relevant to that radar. This tutorial was included within this report as simple, non-technical descriptions of subject areas followed by technical analyses which include relevant graphs, tables, and explanations of the computer model.

FOREWORD

This investigation was performed by personnel of the Radar and Instrumentation Laboratory of the Engineering Experiment Station at the Georgia Institute of Technology in Atlanta, Georgia. Dr. Robert N. Trebits served as Project Director, and Mr. Eric S. Sjoberg served as Associate Project Director of this investigation, designated Georgia Tech Project A-2143. This program was sponsored by the Naval Electronic Systems Engineering Center in Vallejo, California under Contract No. N00228-78-C-2215. Mr. Greg Stovall served as Project Engineer for the Navy.

This technical report covers the work which was performed during the contract period May 1978 through June 1979. The authors of this report include R. N. Trebits, E. S. Sjoberg, and B. C. Appling. The guidance provided by NAVELEX personnel has also been appreciated, with particular acknowledgement directed to Mr. Charles Gill and Mr. Richard Wilz.

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SECTION 1
INTRODUCTION AND TECHNICAL BACKGROUND

1.1 Perspective

The technical thrust of this investigation was to quantitatively determine the theoretical aircraft tracking accuracy limitations of the AN/TPN-22 radar. This radar is the precision approach radar (PAR) for a Marine Corps automatic landing system, currently under engineering development. This radar employs a novel tracking technique, called edge tracking, and electronically scans using a phased array antenna and frequency diversity.

Both elevation and azimuth radar tracking error limitations were determined using statistical analysis procedures. Error contributions were determined for identified phenomenological effects over appropriate aircraft ranges and a specified flight trajectory. Total elevation and azimuth radar tracking errors were then calculated from these individual contributions. Sources of significant errors were then identified as candidates for improvement in a modified radar system. Specific recommendations for effecting tracking improvements were made, along with estimates of improved tracking performance which would result from implementation of these system modifications.

1.2 Technical Background

Two generic aircraft landing system concepts have been employed to provide guidance under adverse weather conditions. The first type of system employs radio transmission of spatially coded signals from a ground installation. Electronic equipment aboard the aircraft then determines positional information relative to a prescribed approach path by appropriate decoding of this signal, thereby defining an "air-derived" landing system. The second type of system employs a ground-based sensor, such as a radar, to track the aircraft. Flight path correction instructions are then transmitted back to the aircraft, defining a classic "ground-derived" landing system.

The major U. S. air derived system, used by the Air Force and in civil aviation, is the VHF/UHF Instrument Landing System (ILS) adopted as an international standard in 1949 by the International Civil Aviation Organization (ICAO). The ground-derived concept is embodied in various U. S. military ground-controlled approach (GCA) systems, all of which use a precision approach radar (PAR) as the sensor element to determine aircraft position during the approach. It is also embodied in various non-radar systems, either operational or under development abroad.

It has been determined that present day landing system requirements necessitate upgraded performance capabilities, including aircraft space management, multiple aircraft control, greater reliability, improved accuracy, and all-weather landing. The VHF/UHF ILS is deficient in necessary aircraft position accuracy, data processing capability, and operational reliability. GCA systems are deficient in data processing/flow and in the precision of the radar sensor, which is essentially a reflection of dated radar technology.

Realization of these deficiencies culminated in the Federal Aviation Administration's establishment of the National Plan for Development of the Microwave Landing System (MLS). The thrust of the plan was the selection of an air-derived landing system operating in the microwave region for the next generation MLS standard. It was realized, however, that the full acquisition and implementation of MLS equipment at all civil and military air bases and on aircraft could take many years. In this transition period several other on-going system developments were recognized and tolerated. Ultimately it is hoped that MLS will prevail, but in the near term development of other automatic landing systems are accepted by the National MLS Plan.

The Marine Air Traffic Control and Landing System (MATCALS) is one of the military, ground-derived landing systems whose development is recognized within the plan. MATCALS is being developed by the Naval Electronic Systems Command for use at Marine, tactical, expeditionary airfields and is designed to provide automated terminal area air traffic control and all-weather, ground-derived, landing control.

MATCALS comprises several elements which together provide all functions required for handling high density air traffic at expeditionary air bases under all-weather (up to approximately 1 inch per hour rainfall) conditions. The functions include landing aircraft automatically as well as by instruments or voice, providing air surveillance, and providing an operations van. The van is used as an interface to the Air Traffic Control tower and meteorological system as well as equipment for communications and data transfer.

For landing control, MATCALS provides the following Navy/Marine Corps landing modes:

a. Mode I: Fully coupled automatic control to touchdown.

b. Mode IA: Fully coupled automatic control until pilot visually acquires the runway, at which point the pilot completes the landing.

c. Mode II: Pilot-controlled approach, with guidance cues provided by cockpit displays such as a cross-pointer indicator or head-up display, and ground-air data link by TADIL-C.

d. Expanded Mode II: Pilot-controlled approach, like Mode II, but with ground-air data link provided by pseudo-ILS, voice channel link, or others which use existing communication equipment in the aircraft.

e. Mode III: Pilot-controlled approach with guidance cues provided by a ground-based operator in the classic GCA talk-down procedure.

The MATCALS is functionally organized into three system segments:

a. Air Traffic Control Subsystem (ATCS)

b. All-Weather Landing Subsystem (ALS)

c. Control and Central Subsystem (CCS)

The ALS serves as the data acquisition segment of MATCALS and includes a radar sensor, mini-computer, landing monitor display, and a landing monitor transmitter. The entire ALS is technically referred to as the Marine Precision Approach and Landing Radar, with a military designation AN/TPN-22. In the AN/TPN-22, the concept is to perform automatic landings while operating in a track-while-scan mode. This is accomplished through use of real time digital filtering algorithms implemented within the system's general purpose mini-computer.

A time multiplexing technique is employed by the AN/TPN-22 such that up to six approaching aircraft can be tracked simultaneously. A large planar array of radiating elements creates an inertialess scanning antenna, which forms a single pencil beam that can be stepped in small increments over the desired area during the search operation. Frequency diversity is utilized to control the elevation angle of the beam, while phase shifting of the radiating array elements controls the beam's azimuth position. The search pattern is momentarily interrupted several times each second to perform a rapid, precision track scan of the anticipated position of up to six aircraft.

Previous Georgia Tech efforts have included an extensive analysis of the phased array antenna for the PAR. These studies included investigations in the areas of state-of-the-art ferrite phase shifter resettability, beam steering errors due to phase command quantization, quantization sidelobes and their reduction, and near-field beam distortion.

In addition to the PAR antenna analysis, an investigation examined the relative advantages of alternative Air Surveillance Radars (ASR) that can provide the ATC function of MATCALS requirements. Critical parameters include the beamwidth, scan rate, and Moving Target Indicator (MTI) technique. Areas of concern were probability of detection at maximum range, tracking accuracy, MTI performance in high vegetative clutter as well as rain, and in providing a weather mapping capability.

The objective of this particular program was thus to investigate and evaluate the tracking concept utilized by the MATCALS precision approach radar. A detailed statistical error analysis of the AN/TPN-22 radar system was undertaken by computer modeling of individual sources of tracking error. The various types of tracking error sources include signal-to-noise ratio, target scintillation and glint, tracking filter lag, ground/sea clutter, multipath interference, and granularity/instrumentation effects. The outputs of this AN/TPN-22 computer tracking model were characterizations of individual elevation and azimuth channel tracking errors as a function of range for various appropriate parameter values. Net elevation and azimuth tracking errors were also calculated by appropriate summation of the individual error contributions.

A management oriented, tutorial description of tracking radar system concepts and applicable tracking error sources was prepared and presented. Particular emphasis was placed on the edge track technique employed by the AN/TPN-22 radar system and those phenomenological and system error sources particularly relevant to that radar. This tutorial has been included within this report in its intended form: simple, non-technical descriptions of subject areas followed by technical analyses which include graphs, tables, and explanations of the computer model.

1.3 Conclusions

Georgia Tech has determined that the edge-track technique, as employed by the AN/TPN-22 radar system, is a feasible technique for an automatic landing system. The total elevation tracking error was determined to be dominated by the induced scintillation caused by the frequency scanning employed in the elevation plane. No single source dominates the azimuth error; different terms dominate at different ranges. The analysis indicates that the tracking errors may be significantly improved by a suitable choice of tracking filter characteristics and radar update rate. This area was recommended for further investigation. Sensitivity studies illustrate that the analysis techniques employed are very sensitive to certain assumptions and parameter values; it was thus recommended that additional effort be expended to validate and update these assumptions and parameter values. Additional conclusions and recommendations are contained throughout the text and are summarized in Section 8.

SECTION 2
TRACKING RADAR SYSTEM DEFINITION

An examination of the phrase "Tracking Radar System" is helpful in identifying traits which tracking radar systems must have. A "Tracking Radar" measures, on a more or less continuous basis, the position of a target; that is, it establishes a track on the target. The use of electromagnetic energy for making these measurements is implied by the word radar. Note that the radar itself may be active (transmit and receive energy) passive (receive only), or cooperative (interrogate a beacon on the target). One or more targets may be tracked simultaneously, but a new position measurement must be made for each target on a regular basis. If this is not done, then the tracking radar will not have a good estimate of the target's position. Note that the position measurement must include range, elevation, and azimuth (bearing) information and may include doppler data.

The final word, system, indicates that the positional information inherent in the radar data will be extracted, processed, and perhaps used to control some process. Historically, tracking radars have found the most use in weapons control, missile range instrumentation, and aircraft guidance systems. Processing of the radar data yields a current position estimate for the target. By utilizing several previous position measurements, velocity and acceleration estimates may be computed. Combining this information with known physical parameters (e.g., conservation of momentum, stress limits on aircraft, etc.) future estimate of the target's position may be calculated. It is for this reason that regularly updated measurements are required. In general, for a given radar system, as the measurement rate is increased, the accuracy of the position estimate is improved and the tracking error is decreased.

SECTION 3
TRACKING TECHNIQUES, HISTORICAL DEVELOPMENT

The earliest radar tracking technique was simply an operator watching a display and marking target positions with a grease pencil. This method, though simple, was inaccurate and could be easily overloaded. Today's tracking radars employ digital processing to extract the maximum information from the radar signals. In addition, tracking techniques have been developed which minimize some of the inherent system errors. Some of these techniques are described below. (The described methods are all active.)

3.1 Search Scan Track/TWS Radar

One of the first radar tracking techniques developed is designated Search Scan Track or Track-While-Scan (TWS). As the name implies, tracking is accomplished as the radar scans, typically over a full 360 degrees of azimuth. Hence, this technique is not a true dedicated tracking radar but does provide a gross target position estimate while also searching a large volume. An application of this type of radar system is the vectoring of interceptor aircraft to the position of unfriendly aircraft. During World War II, the British used this type of radar for just such a purpose during the Battle of Britain. The discussion that follows will be limited to ground-based TWS radar systems.

The system design goal of all tracking radars, that target position be accurately specified in range, azimuth and elevation, must be met by the TWS class of radars. A target's azimuthal position is straightforwardly determined by noting the relative azimuth angle (bearing) of the antenna when the target is detected. Range to the target is determined from the elapsed time from signal transmission to reception of the target echo signal (considering active radars only for this case).

Determination of the elevation angle of the target requires more than a simple fan beam (single radar beam narrow in azimuth extent but wide in elevation). Three methods of determining target elevation have been used, including V-beam, three dimensional scanning, and stacked beam radars. The first two techniques were developed in the 1940's and used during World War II. The V-beam technique employs two fan beams, one oriented vertically and the other at 45 degrees with respect to the first, as shown in Figure 3-1. Target range and azimuth are determined conventionally by the vertical beam, while target elevation is proportional to the difference in time of arrival (or angle of antenna rotation) between the target return signals in the vertical and the slanted beams.

A three dimensional scanning radar scans a pencil beam (narrow in azimuth and elevation) in a raster pattern over the search volume, as shown in Figure 3-2. The target is illuminated only when the beam is pointing directly at the target. This may be accomplished by mechanically scanning a pencil beam antenna or electronically steering a beam, as in a phased array antenna. Hence elevation, azimuth and range information are directly available. Stacked beam radars are similar to the three dimensional scanning types in that elevation coverage is obtained with separate pencil beams, as shown in Figure 3-3; however, the stacked beam radar employs several (5-20) beams oriented vertically atop each other. This set of beams then is scanned in a conventional azimuthal manner. Each of the individual receiver channels then processes the signal from one beam. When a target is detected, the channel containing the largest target signal is designated, and the elevation angle associated with that channel is assigned to that target. The stacked beams may be formed either by the mechanical design of the antenna or by electronic means, as in a phased array radar.

3.2 Conical Scan Radar

The conical scan technique is a true tracking method in that it is suitable only for tracking purposes and performs neither search nor any other function. In this tracking radar technique the radar scans its beam in a circular motion about the target, as shown in Figure 3-4. The conical scan radar system attempts to keep the target in the center of its circular scan by sensing the return signal amplitude at each location in the conical scan around the target. If the target is centered, the target signal amplitude will be constant at all points of the scan. If, however, the target is not centered, the target signal amplitude will vary as a function of the position of the radar beam. Specifically, the target signal will be a sinusoid whose frequency is equal to the conical scan frequency, amplitude proportional to the magnitude of the positional error, and phase proportional to the error direction (i.e., azimuth and elevation). The conical scan technique generally employs a mechanically scanned antenna or feed.

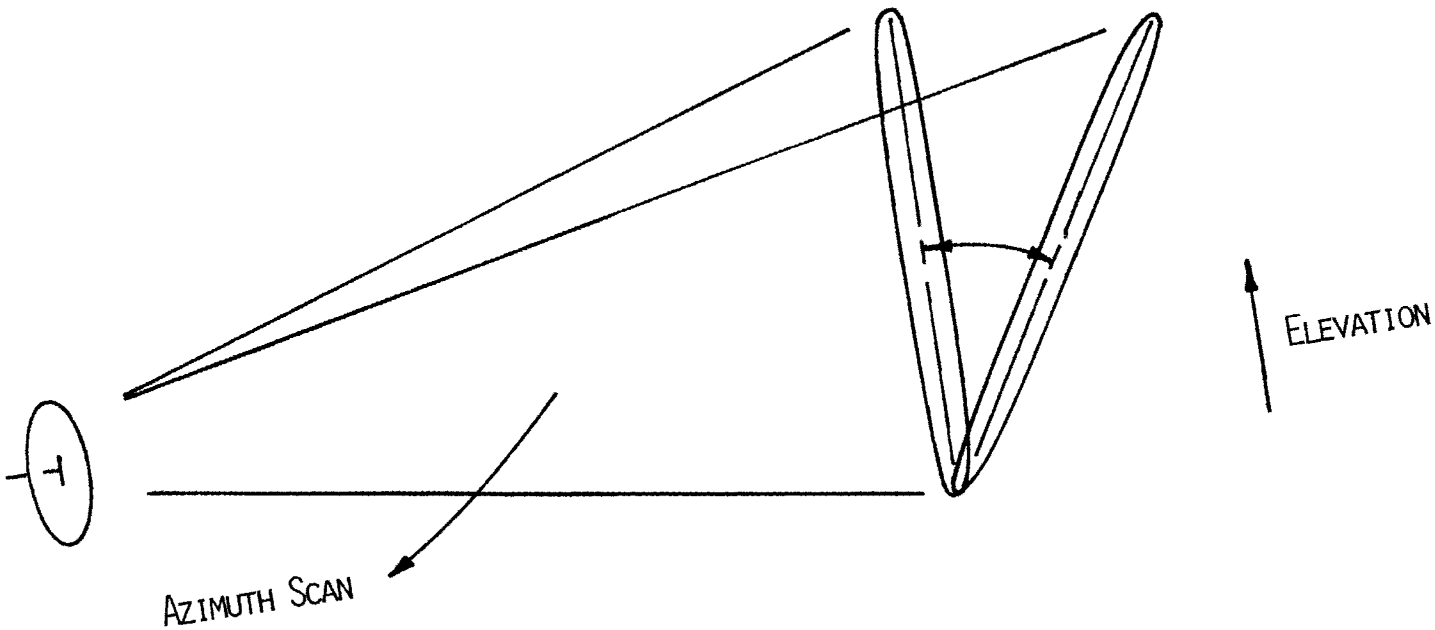

Figure 3-1. V-Beam Radar.

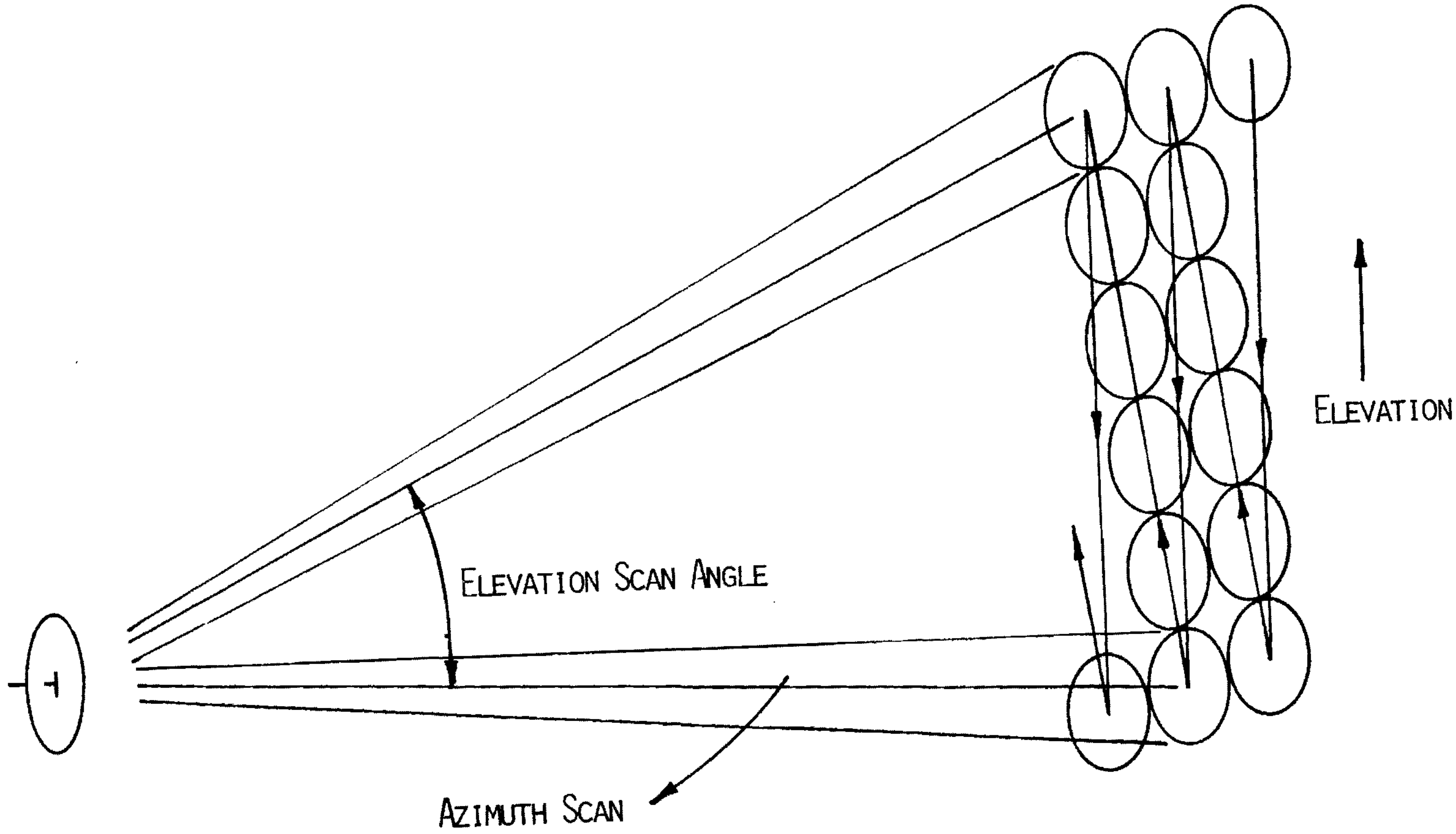

Figure 3-2. Raster Scan Radar.

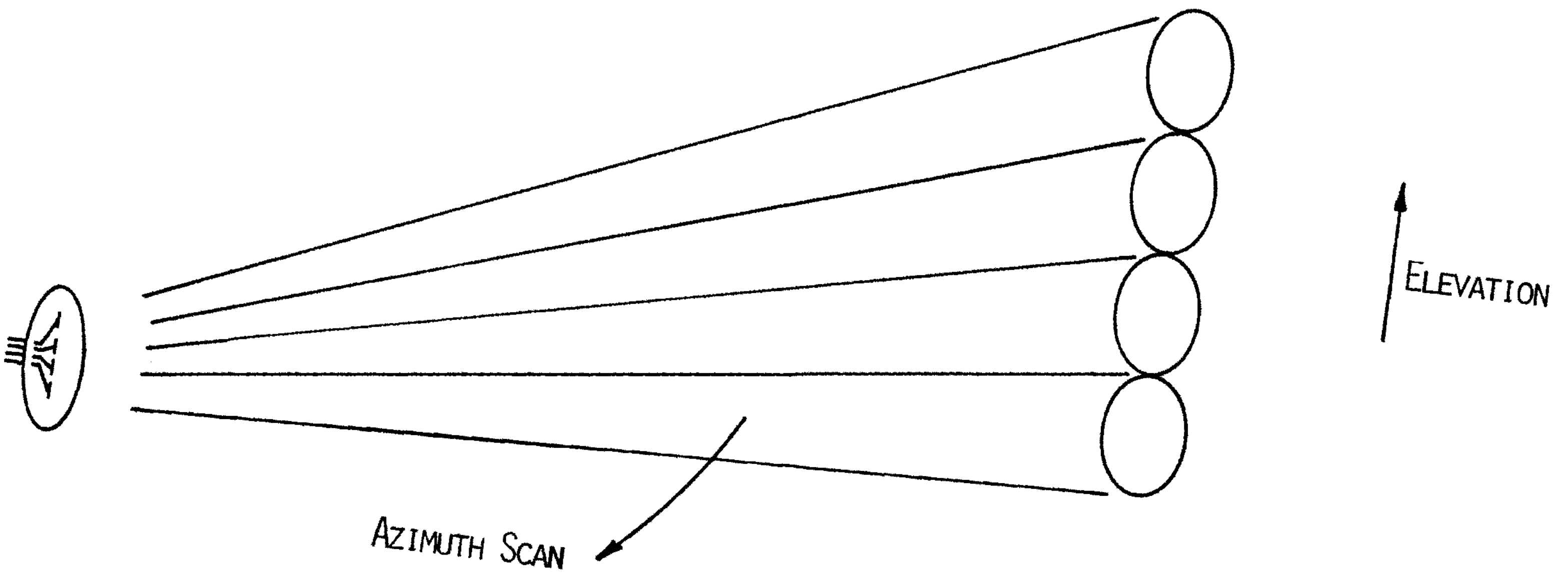

Figure 3-3. Stacked Beam Radar.

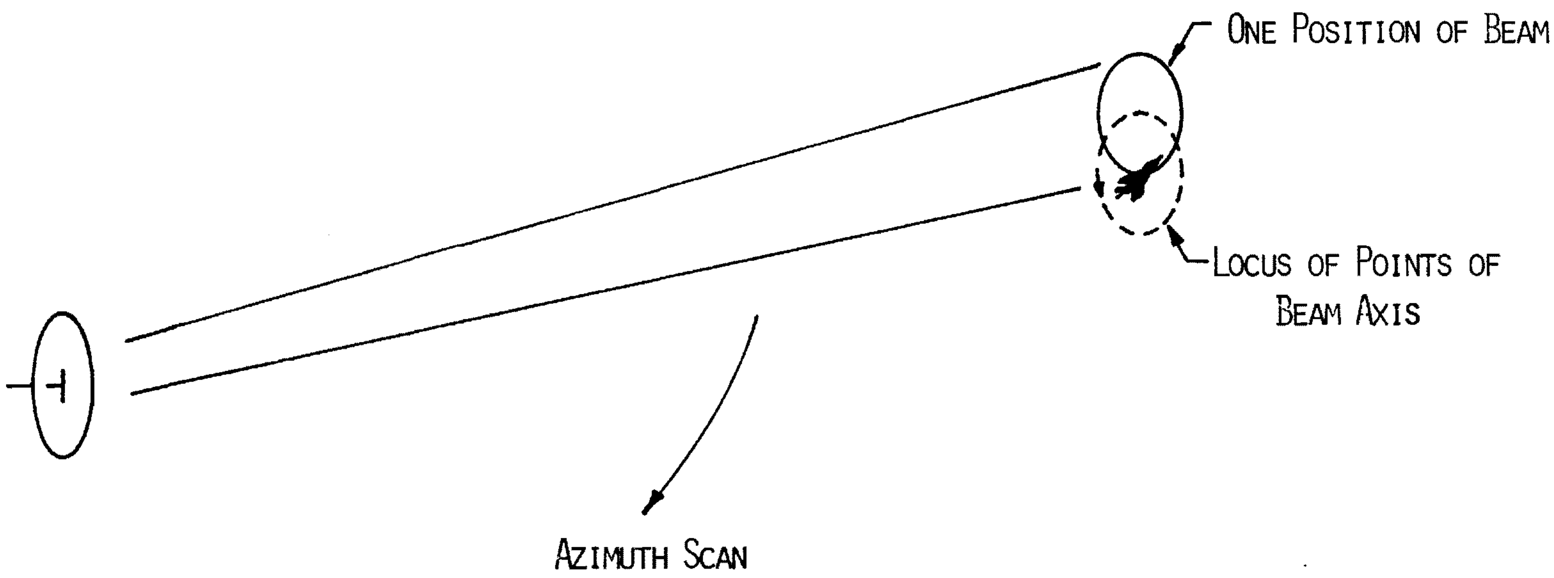

Figure 3-4. Conical Scan Radar.

3.3 Sequential Lobing Radar

A sequential lobing tracking radar is similar to a conical scan tracking radar in that it senses the target return signal in a circular path about the target. However, as its name implies, a sequential lobing system looks only at discrete points on the path as shown in Figure 3-5. At least three points must be sampled to give an unambiguous position estimate, but generally four or more points are used. This method may use either a mechanically positioned antenna/feed or a phased array antenna.

3.4. Monopulse Radar

Conical scan and sequential lobing radars provide a significant improvement in tracking accuracy over track-while-scan techniques. However, both techniques suffer from a common problem: the target signal level can vary for reasons other than the beam position of the radar. This signal variation, termed scintillation, can have many causes, which will be discussed in the following section. A solution to the target scintillation problem is to use a simultaneous lobing technique, where the radar forms four beams surrounding the target as shown in Figure 3-6. The radar's processor senses the amplitudes (or relative phases) from the four beams, just as it would for a sequential lobing radar, then determines the antenna pointing corrections required to center the target. As might be expected, this type of radar is more complex than the previously mentioned dedicated tracking techniques, but where tracking accuracy is a must, this technique provides superior performance.

3.5 Edge Track

Edge tracking is a new tracking technique and is employed by the AN/TPN-22 radar system. In operation, the radar scans a narrow pencil beam in a cross pattern across the target, one scan vertical and another horizontal, as shown in Figure 3-7. The AN/TPN-22 employs a frequency/phase scanned antenna using frequency to position the beam in elevation and phase to position the beam in azimuth. This cross scan enables the radar processor to determine the position of the four outer edges of the target in relation to the scan pattern. The four edge position estimates plus a range measurement are filtered, and the center of the target is determined by averaging the filtered edge estimates.

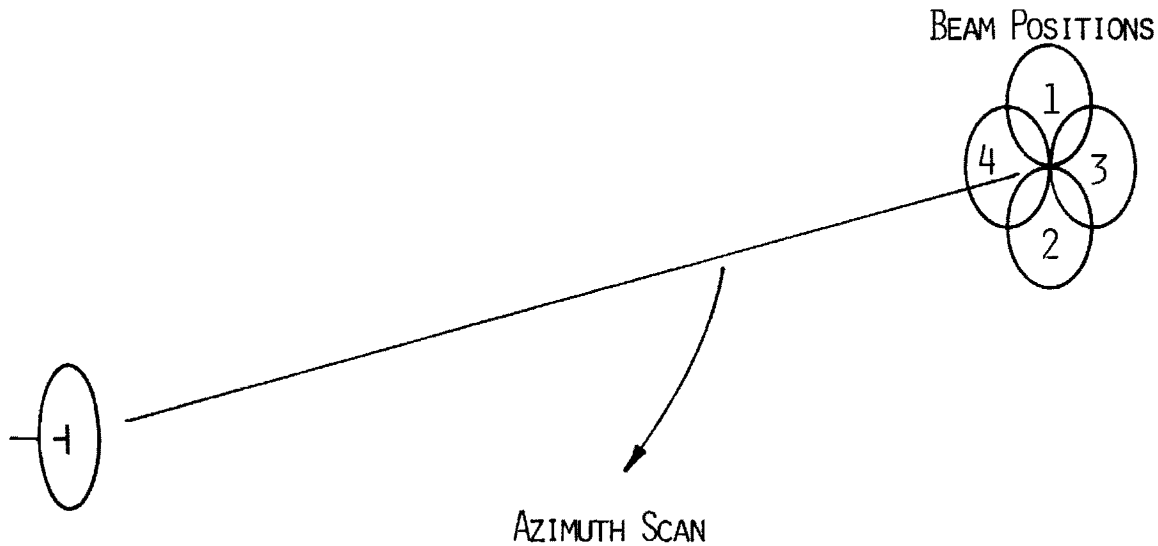

Figure 3-5. Sequential Lobing Radar.

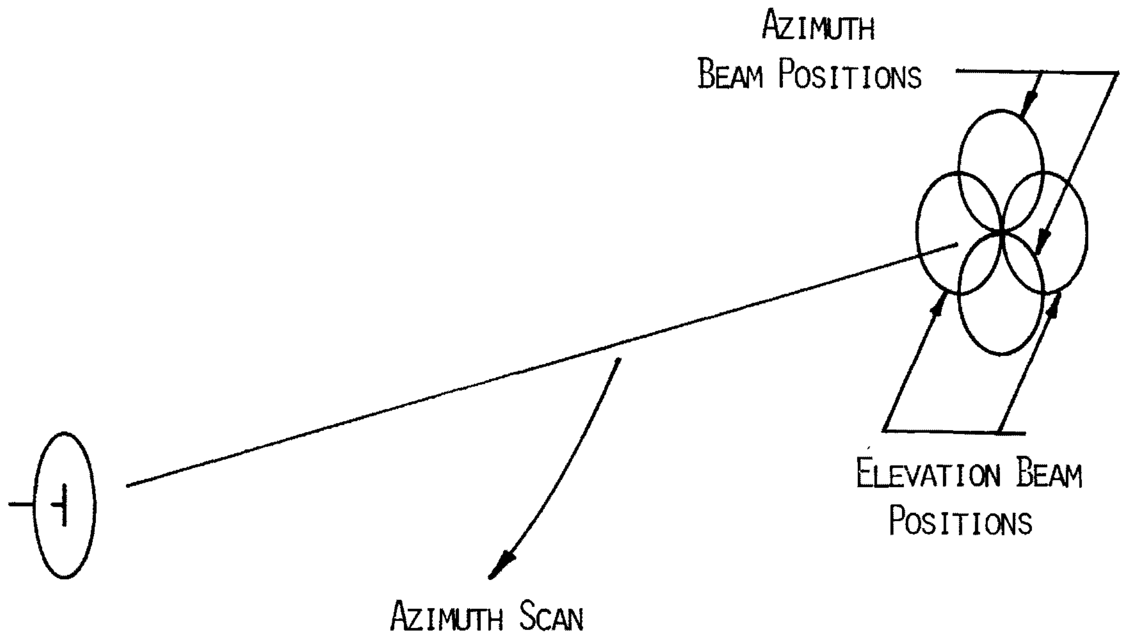

Figure 3-6. Monopulse Radar.

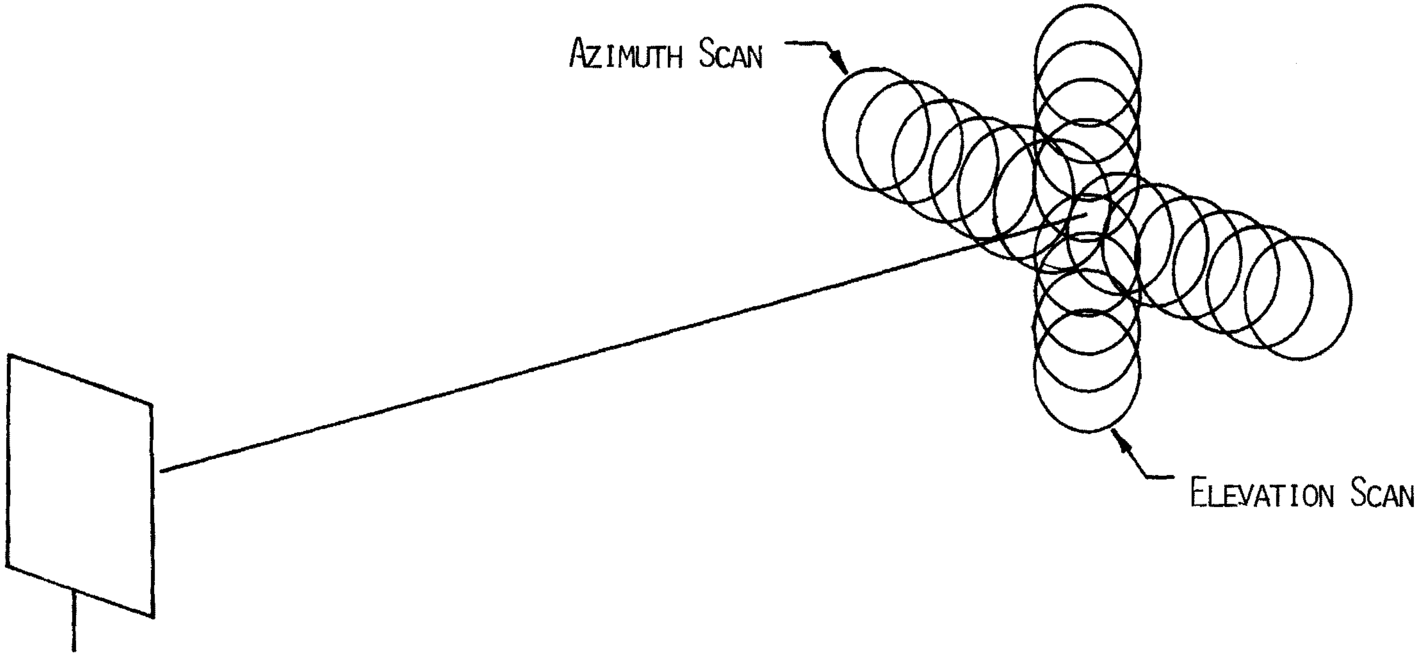

Figure 3-7. Edge Track Radar.

This edge technique offers several potential advantages. It may reduce target scintillation errors by illuminating only a single dominant scatterer when the edge is detected. Glint errors, which are also caused by the returns from several scatterers adding constructively and destructively, may also be reduced for the same reason. However, depending on the relative radar returns from the different scattering centers, the actual target edge may not be resolvable, in which case a tracking error may result.

SECTION 4

FACTORS WHICH LIMIT TRACKING PERFORMANCE

The accuracy of any tracking radar system is limited by a combination of many factors. The actual design implementation of the radar system determines what contribution each of the factors makes to the overall system tracking error. There are three basic error sources for the AN/TPN-22 radar system: (1) errors introduced by the radar, (2) errors caused by the target, and (3) environmentally induced errors.

Errors introduced by the radar include:

a. signal-to-noise ratio limitations,

b. instrumental/granularity effects,

c. track filter/servo bandwidth lags.

Target induced errors include:

a. scintillaion, or radar target signal amplitude fluctuation,

b. glint, or fluctuation in the apparent direction of arrival of the target signal.

Finally, environmental effects which may cause tracking errors include:

a. clutter, both surface clutter and rain/fog clutter,

b. multipath interference.

A fourth source of errors which should not be a limiting factor for the AN/TPN-22 in its general use is jamming and electromagnetic interference. Each of these factors will be defined and discussed briefly in the following paragraphs. Refer to Figure 4-1 for an illustration of the effects of the different error sources.

4.1 Signal-to-Noise Ratio

The term signal-to-noise ratio refers to the ratio of the desired signal energy divided by the radar system self-noise energy. These two terms require additional explanation. The desired signal energy is the energy reflected from the target of interest toward the radar and is dependent on the amount of energy transmitted by the radar, the orientation of the target with respect to the axis of the radar beam, and the amount of energy reflected from the target back to the radar. The received signal energy varies as a function of range to the target, aspect angle of the target,

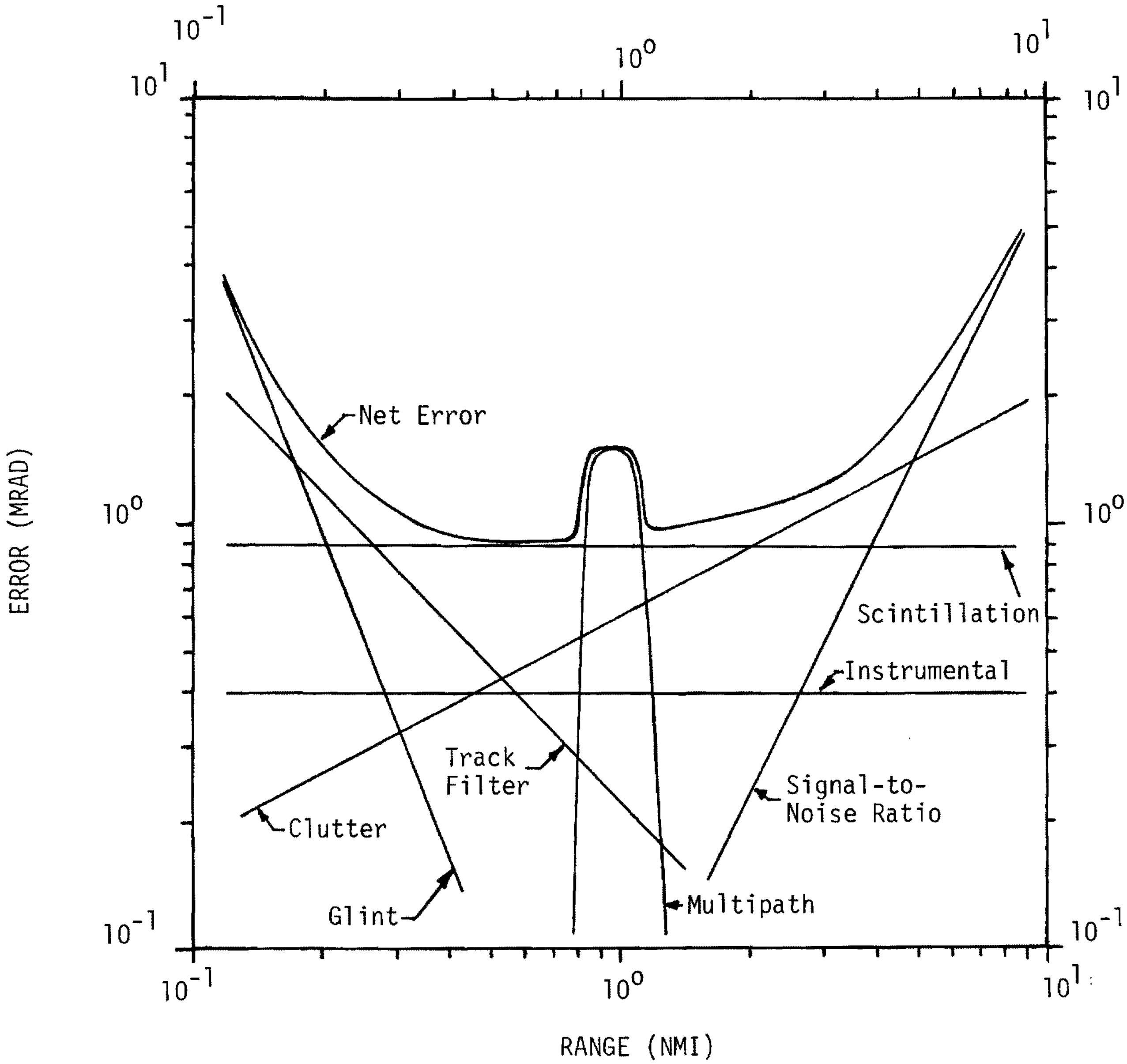

Figure 4-1. Typical Errors for a Tracking Radar System.

etc. The self-noise energy of the radar system, on the other hand, is a constant which depends entirely on the design of the radar system, with a lower limit determined by physical laws. This noise is usually white; i.e., having uniform spectral content. Also generally included in the signal-to-noise ratio calculations are the radar system losses, including losses due to imperfect electronic devices, mismatch losses in the RF plumbing and between amplifier sections, and ohmic losses.

The returned signal energy decreases with increasing range and, hence, the signal-to-noise ratio decreases also. The decreasing signal-to-noise ratio has the effect of increasing tracking errors, that is, decreasing tracking accuracy. It is easy to see why this is the case. Tracking in essentially a process of measuring a certain parameter of a signal. When that signal is sharp and precise, the measurement can also be precise. However, when the signal is corrupted by noise, the measurement becomes less precise. As can be seen from Figure 4-1, the signal-to-noise ratio is the limiting factor on tracking accuracy at long ranges.

4.2 Instrumental/Granularity

Instrumental/granularity factors place an absolute limit on the measurement accuracy of the radar system. Whereas all other error sources are dependent in some manner on external variables, the instrumental errors are totally determined by the radar system. Types of errors which are included here include:

a. Number of bits in digitial processor.

b. Minimum signal levels and dynamic range of analog circuits.

c. Beam step granulation in phased array systems.

d. Resolver accuracy for mechanically scanned systems.

e. Tolerances on mechanical components, i.e., antenna, roller path inclination (mechanically scanned systems) etc.

f. Sampling rates (i.e, PRF, D/A conversion rates, and range gate widths).

g. Radar beam pattern.

h. Long and short term stability of components (i.e., temperatue coefficient, aging effects).

This list is by no means complete but is intended to illustrate some of the factors which influence ultimate system accuracy. Also note that the error level associated with each of the above factors is determined during the radar system design as a trade-off between desired accuracy versus time and cost. The effect of instrumental errors is a constant with range, as shown in Figure 4-1.

4.3 Track Filter/Servo Bandwidths

The track filter/servo system of a tracking radar has the function of using data from the radar to accurately locate the target and predict its future position. This information is used to align the antenna beam with the target for the next postion determination and to perform the function for which accurate tracking data are required (e.g., fire control, missile tracking, automatic aircraft landing systems).

In a mechanically scanned radar, the servo system typically consists of motors, gearing, position and rate feedback, as well as the antenna and support structure. The mechanical design of the system determines to a large extent the capability of the radar to track maneuvering targets. The system's maximum potential performance is determined by how fast the antenna can be slewed and stopped reliably with precision. Electronically steered antennas, on the other hand, have no such mechanical restrictions. Their response time is determined solely by the tracking equations implemented in the tracking computer.

Desirable characteristics of the servo loop are described very succinctly in Chapter 21 of the Radar Handbook by Merrill I. Skolnik and are repeated here:

> "It is desired that the antenna beam follow the center of the target as closely as possible, which implies that the servosystem should be capable of moving the antenna quickly. The combined velocity and acceleration characteristics of a servosystem can be described by the frequency response of the tracking loop, which is essentially a low-pass filter characteristic. Increasing the bandwidth increases the quickness of the servosytem and its ability to follow closely a strong, steady signal. However, a typical target causes scintillation of the echo signal, giving erroneous error-detector outputs (Sec. 28.3), and at long range the echo is weak, allowing receiver noise to cause additional random fluctuations in the error-detector output. Consequently, a wide servo bandwidth which reduces lag errors allows the noise to cause erroneous motions of the tracking system. Therefore, for best overall performance, it is necessary to limit the servo bandwidth to the minimum necessary to

maintain a reasonably small tracking lag error. There is an optimum bandwidth that minimizes the rms of the total erroneous outputs including both tracking lag and random noise, depending upon the target, its trajectory, and other radar parameters."

"The optimum bandwidth for angle tracking is range-dependent. A target with typical velocity at long range has low angle rates and a low SNR, and a narrower servo passband will follow the target with reasonably small tracking lag while minimizing the response to receiver thermal noise. At close range the signal is strong, overriding receiver noise, but target-angle-scintillation errors proportional to the angular span of the target are large. A wider servo bandwidth is needed at close range to keep tracking lag within reasonable values, but it must not be wider than necessary or target scintillation errors become excessive."

The plot of servo error versus range (Figure 4-1) assumes constant bandwidth of the track filter/servo system. Consequently, the lag errors increase with decreasing range due to the larger angular velocity and acceleration terms.

4.4 Scintillation

A radar usually processes the total echo signal received from a target. Because of the complex shape of most targets the total radar echo is composed of the vector sum of the returns from many scattering centers. These scattering centers (or scatterers) are typically located at the junction of surfaces of the target such as at the air intakes, pods under the wings, etc., and, when landing, from the landing gear. The radar cross-section (RCS) of these scatterers depends on the aspect angle of the aircraft with respect to the radar and the polarization and frequency of the radar. Thus the overall radar return signal is a very complex function which usually cannot be reliably predicted in advance.

As the aircraft flies, the positions of these scatterers move in relation to the beam axis. Although the movements may be small, it takes only a one quarter wavelength shift to cause a 180 degree phase change between two scatterers. (At the 9.2 GHz frequency (X-band) of the AN/TPN-22, one quarter wavelength corresponds to about 0.8 cm, or about 5/16 inch). As the relative amplitude of the different scattering centers vary and the phase angles change, the amplitude of the vector sum necessarily changes. This amplitude variation is known as scintillation.

Scintillation may be divided into two classes, low and high frequency. Low frequency fluctuations are caused by gross target motion and are generally restricted to under 5 Hz at X-band. Higher frequency components are due to aircraft vibration and returns from propellers or turbine blades. This component may extend up to several thousand Hertz at X-band.

As shown in Figure 4-1, the average effects of scintillation are constant with range. Actually, however, the scintillation errors will vary with range, but in a somewhat random manner. The graph shows the expected mean error due to scintillation.

Radars which use frequency to control the beam position will induce scintillation in the target signal as the frequency changes. This is again due to the RCS of each scatterer changing as a function of frequency and the spacing between scatterers changing relative to a wavelength. The frequency shift required to cause a one quarter wavelength shift between two scatterers separated by ten meters is given by

$$\Delta f = \frac{.25c}{10\text{m}} = \frac{.25 \times 3 \times 10^8 \text{ m/sec}}{10\text{m}}$$

$$\Delta f = 7.5 \text{ MHz}$$

This represents the frequency change required for a complete decorrelation. Significant scintillation effects will also be induced for frequency changes of less than this amount.

4.5 Glint

As defined here, glint is the fluctuation in the apparent target angular position. This is due to the same phenomena which causes scintillation, i.e., returns from two or more scatterers adding in or out of phase. Figure 4-2, taken from Skolnik's Radar Handbook, 28-9, illustrates the theoretical and measured angular error for a two reflector target where the two echos have different amplitude and phase. Note that for some conditions, the apparent position of the target may fall outside the physical extent of the target.

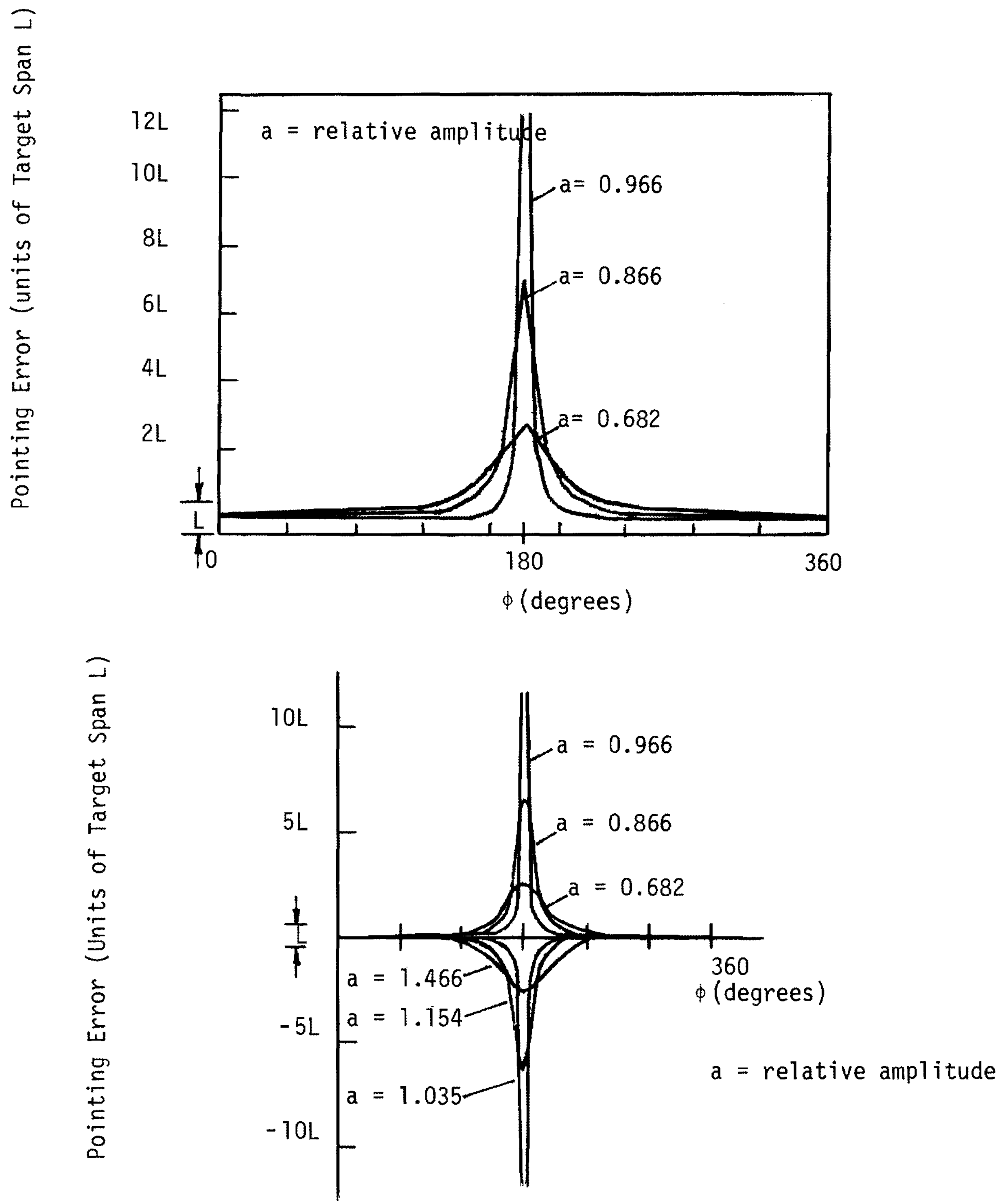

Figure 4-2. Measured (Upper) and Calculated (Lower) Angular Error for a Two Reflector Target Spanning Distance L.[6]

Glint errors typically fluctuate randomly at a relatively low frequency (less than about 20 Hz) and many times have Gaussian amplitude distributions. The lateral variance in the target centroid is proportional to the target's physical dimension and is relatively constant with range, thus causing the angular error to increase with decreasing range.

4.6 Clutter

Ground or sea clutter competes with the return from the target as a source of amplitude and angle noise. At the same range as the target, the ground or ocean will reflect energy transmitted from the antenna as shown in Figure 4-3. If the main beam of the antenna intersects the ground at the range of the target, the reflected clutter power may be especially high, perhaps dominating the power reflected from the target.

The clutter signal itself has an amplitude distribution and a power spectral density which depends on the terrain type or sea state, the incidence angle and the radar frequency. The clutter return signal can create signal fading, or scintillation, from the desired target due to interference effects and glint due to the apparent shift in the target.

Within the main beam of the antenna, the radar cross-section of the clutter is range dependent, since the illuminated area on the ground (or sea) for near grazing incidence is proportional to range, beamwidth, and pulse width. Thus at farther ranges the clutter cell radar cross-section increases, if incidence angle effects and the curvature of the earth are ignored, and the target-to-clutter signal ratio correspondingly decreases, assuming that the target is totally within the main beam. At nearer ranges the main beam clutter radar cross-secion is smaller, but energy reflected from nearby buildings or large land features via antenna sidelobes may become large enough to affect target tracking adversely.

Volume clutter from various types of hydrometeors (rain, hail, sleet, snow, etc.) can create the same noiselike effects as can ground clutter regarding target tracking. For this type of clutter the radar cross-section is proportional to the range squared, for complete beamfill. Additionally, the presence of solid and/or liquid precipitants in the atmosphere between the radar and the target will result in a significant attenuation of signal power. This two-way attenuation will decrease

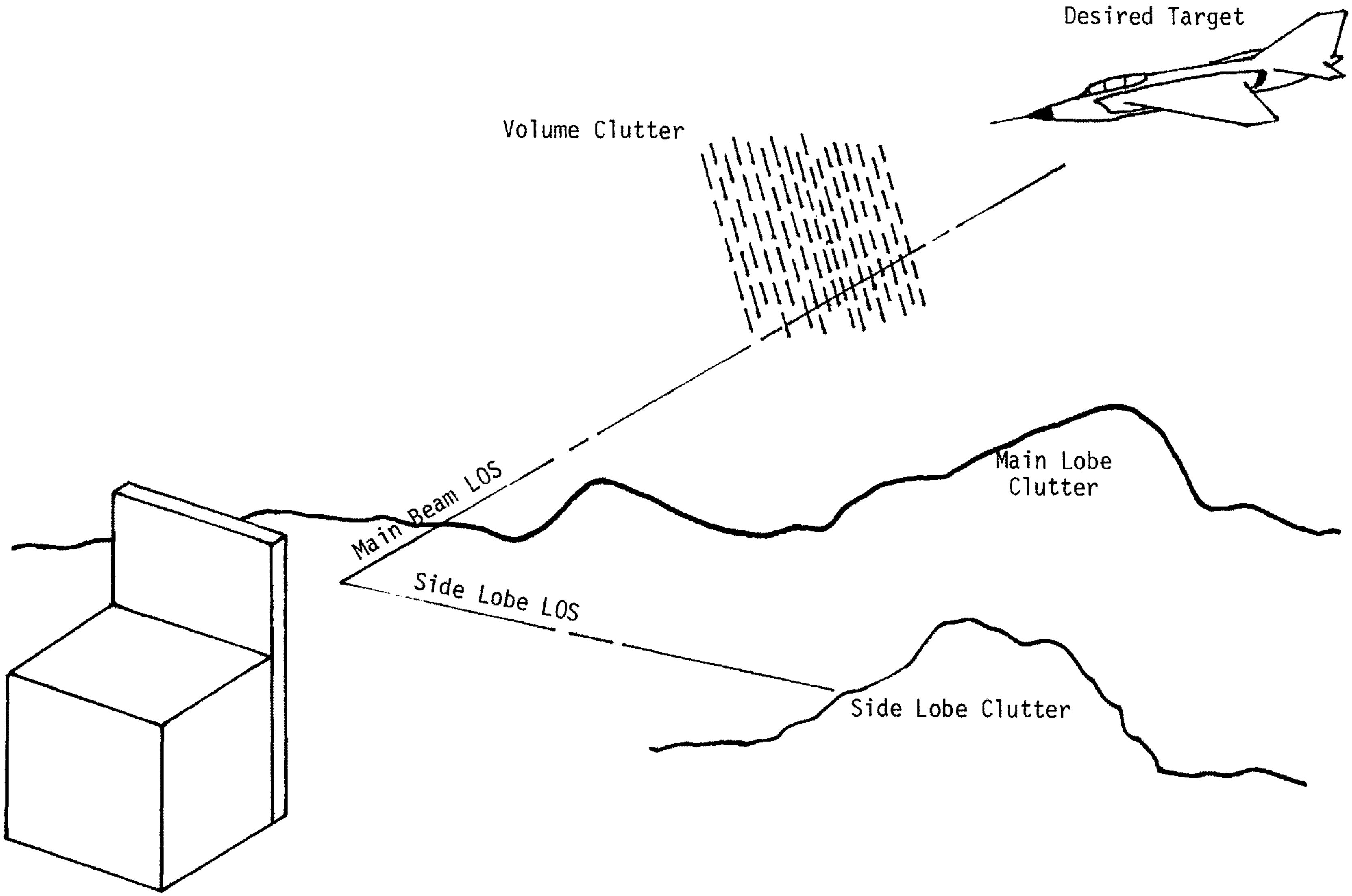

Figure 4-3. Sources of Clutter Returns: Main Beam, Side Lobe, and Volume Clutter.

the signal-to-noise power ratio at all ranges, thereby further degrading tracking performance.

4.7 Multipath Interference

Multipath interference effects are the result of the radar signal having traveled to the target and back to the receiving antenna by paths other than the direct path. Figure 4-4 shows the four round-trip paths that may be traversed by an electromagnetic wave as it travels from the radar to the target and back again. A manifestation of the occurence of multipath interference is the appearance of a dual-source condition of angle noise with regard to angle tracking. Especially prevalent at low grazing angles, this effect can cause the radar to angle track a target image rather than the target itself.

In tracking applications at low grazing angles over the ocean surface the target image may be below the horizon. Angle track error will then be severe in target elevation estimation and may be present in azimuth also if there is inadequate isolation between receiver elevation and azimuth channels. Over nonflat terrain or near buildings, multipath interference may even occur in the azimuth channel predominantly.

Pheonomenologically those rays which have been singly or doubly reflected suffer a phase shift relative to the direct ray due to both the reflection and to the path length difference. The resulting interference of the direct ray with the reflected rays results in a lobing pattern of received power which functionally depends on the incidence angle, the surface roughness, and the radar wavelength. Surface roughness itself is a relative term and depends on incidence angle and radar wavelength.

4.8 Electromagnetic Interference

Two distinct sources of electomagnetic interference are relevant to discussion of a tracking radar, namely (1) other radars operating within the same frequency band and (2) signal jamming by unfriendly forces. The first source is, of course, unintentional interference and can be avoided through careful frequency allocation and management. The second source is, just as obviously, quite intentional by an unfriendly force, and is intended to defeat radar operation or possibly create erroneous tracking information.

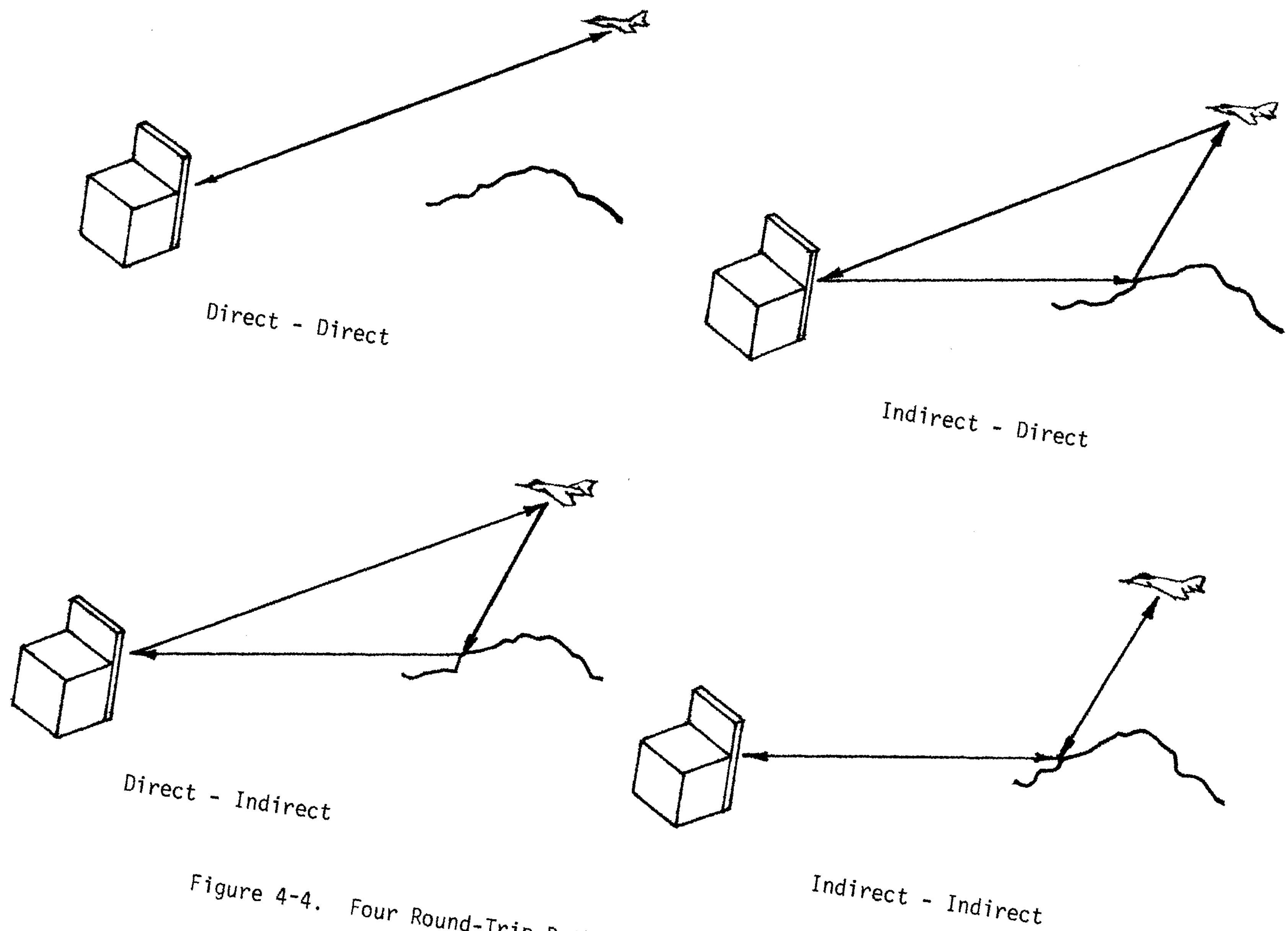

Figure 4-4. Four Round-Trip Paths to the Target, Showing Multipath.

Nearby system interference can occur when two radar systems have operating frequency bandwidths with sufficient overlap so that each can receive energy transmitted from the other. For monopulse and conical scan systems, range gate errors can occur due to the presence of erroneous received pulses in the tracking gates. If the interfering system has a pulse repetition frequency equal to or a multiple of the victim PRF, gate stealing can occur, especailly if timing oscillators are very stable. Otherwise range gate jitter will produce noise in the range track. If the interfering signal is too strong, the victim receiver may not have sufficient time to recover fully prior to the tracking gates causing range reduction.

Intentional jamming of a radar is altogether a distinctly different process and must be addressed according to the nature of the jamming signal. In general there are two generic classes of jammers, those that attempt to swamp the victim radar with high quantities of power or many extraneous targets (noise jamming) and those that attempt to cause the victim radar to lock onto a false target (deceptive jamming).

Noise jammers rely on overloading the victim receiver with either excess power levels, saturating the tracking circuits, or with large numbers of randomly produced targets, created by modulating the jammer signal. Countermeasures are incorporated into radars to electronically counteract the action of such jammers and usually employ some sort of filtering of the received signal to separate the desired signal reflected off the target from the undesired jamming signal.

Deception jammers are generally more sophisticated in their approach than noise, or barrage, jammers. The intent is to cause the radar to accurately track an electronically created false target rather than the real target, which desires to remain undetected or untracked. One version seeks to cause the tracking gates to "walk off" a real target slowly so that the loss of time track is unnoticed. This technique is called gate stealing and can be very difficult to counteract since there are numerous techniques which can be utilized to accomplish it.

SECTION 5
LIMITING FACTORS FOR VARIOUS TRACKING TECHNIQUES

5.1 Conical Scan Radar

This technique consists of mechanically rotating a feed or reflector such that the beam in space moves through a conical pattern about the axis of symmetry (boresight). Angular deviations of the target being tracked from the axis of symmetry result in signal levels that are greater in the direction of the target and smaller in the opposite direction. As the beam scans, this signal variation is repeated in a sinusoidal manner. The amplitude of the sinusoid indicates the magnitude of the angle between the line-of-sight (LOS) and the axis of symmetry. The phase with respect to the beam's roational position indicates the direction of the angle. Normally the signal is monitored in two orthogonal directions (e.g., vertical and horizontal). An angular deviation between the LOS and the axis of symmetry (boresight) in any direction may be described by components in two orthogonal planes.

Of the factors which potentially limit tracking performance, the conical scan approach is subject to most of them. As the signal-to-noise ratio becomes smaller the signal which indicates the angle between the LOS and boresight becomes progressively more contaminated by noise and hence erroneous measurements result. In addition, since the beam is always at an angle (squint angle) with respect to the LOS, there is an additional signal loss due to the lower antenna gain in directions other than the beam center direction.

If the targets effective cross section fluctuates in time in such a manner that the cross section is repeatedly high or repeatedly low when the beam is at a particular angular position, an erroneous error signal will result. Seldom will the cross section fluctuations be exactly sychronized with the conical scan position, and the amount of error developed in the radar's determination of target position will depend on how closely the conical scan rate and fluctuation frequency are related. This scintillation error has usually been the final limit on conical scan radar accuracy at the mid ranges where neither glint nor signal-to-noise effects are the limiting factor. Scintillation errors in conical scan radars are usually not strongly dependent on range.

Other errors to which the conical scan technique is susceptible, which are not strongly range dependent, include instrumental and granularity errors. The precision with which the antennas' position is determined, the mechanical slope in the gearing by which the antenna is positioned and the resolution of any positional data conversion (e.g., analog-to-digital conversion of the error signal) are examples of instrumental or granularity error sources.

Glint, the apparent change in the direction from which the signal arrives, results from phase front distortion of the arriving signal. The antenna is most sensitive to glint effects when the boresight line is perpendicular to the phase front. This is not necessarily the LOS to the target. Angular glint is strongly range dependent, since the angular extent of the target is progressively larger for shorter ranges. The error caused by glint is closely related to actual target size, but at times may cause the target's apparent centroid to be outside its actual physical extent. Glint is normally the limiting factor on conical scan radar accuracy at close ranges.

Multipath phenomena causes errors in conical scan radars which are analogous to signal-to-noise, scintillation, and glint errors. If the indirect ray, which is reflected by a surface between the radar and the target, is out of phase with the direct ray, they will tend to cancel resulting in a low signal level. The reduced signal-to-noise ratio will result in larger errors due to noise. If the signal resulting from the direct and indirect signal repeatedly interfere constructively and then destructively, a scintillation type error is induced in the conical scan radar. Finally, depending on the relative strength of the direct and indirect signal and the angle between their direction of arrival, the target may appear to be in the direction of the point of reflection of the indirect signal or in the actual target direction, or a glint-like phenomena may occur wherein the apparent target may be in a direction determined by the apparent phase front orientations of the composite signal. As in glint, the apparent position may be somewhere between the direct and indirect signal directions of arrival and occasionally even outside these bounds.

Clutter signals may mask or contaminate the target signal in a manner similar to noise and occasionally may appear target-like to the radar. If the radar application is to track targets with non-zero relative range rates, doppler processing is usually employed to discriminate against the clutter signal. The surface clutter signal level is strongly dependent on grazing angle, RF frequency, surface roughness, and the resolution cell size, which is determined by the pulse width and horizontal beamwidth at the incidence point. Volume clutter is, in addition, dependent on the vertical beamwidth. Poor sidelobe characteristics can magnify the effects of either type of clutter, but especially that of volume clutter (e.g., rain). In addition, even clutter which is not in the same resolution cell as the target can affect tracking accuracy as a result of range ambiguity phenomena.

Either deliberate or inadvertent electromagnetic interference can cause tracking errors in conical scan radars. The interference can be categorized into two basic categories (i.e., masking and deception). The masking type of interference causes signal-to-noise-like errors by reducing the quasi-signal-to-noise ratio. Hence erroneous tracking signals are derived. Deceptive interference, whether deliberate or inadvertent, fools the radars tracking circuits and processing. The conical scan technique is especially susceptible to deliberate interference or jamming which is synchronized with the scan position. This susceptibility led to the development of Conical Scan on Receive Only (COSRO) techniques. In this technique, only the receive beam pattern is scanned while the transmit pattern is continuously positioned in the boresight direction. This makes it difficult for one to determine the beam (receive) position at any point in time and hence reduces the conical scan radar's susceptibility to synchronized jamming. If the radar has poor sidelobe characteristics, it will also be susceptible to interference through the sidelobes.

Track filters and/or electromechanical servo systems are normally employed with conical scan track radars. The more filtering action they perform, the smoother the track, for a non-maneuvering radial motion or stationary target. A lower bandwidth or longer response time track filter or servo also has the effect of integrating the positional information from many scans. With all other factors equal, this integration has the effect of reducing the tracking error which is due to noise-like scan-to-scan apparent positions. Unfortunately, tracking lags result from angular velocities and accelerations. The amount of lag depends on the type of control implemented, but generally becomes worse under conditions of low effective bandwidths, which are desirable for minimizing other tracking errors. Hence, it is not uncommon to have multiple bandwidths. In the case of track filter estimation techniques such as Kalman filtering, the effective bandwidth is essentially continuously optimized to cause minimum variance in the tracking solution. In any case, there is an apparent dilemma in selecting bandwidths and one must take care to assure that the selection is well matched to tracking requirements.

5.2 Sequential Lobing Radar

Generically, sequential lobe may be viewed as the electronic equivalent of conical scan. There are several important differences, however. One significant difference lies in the more rapid beam position changes. Also, the beam is not moved or scanned in a continuous fashion and the beam is transmitted in a limited number of discrete directions. Theoretically, the beam could sample in as few as three distinct directions and still derive sufficient angular error information.

The sequential lobe technique is subject to signal-to-noise errors in a manner similar to conical scan and also degrades the signal level by virture of making use of a squint angle. The sequential lobe is generally less susceptible to scintillation effects because the target's position is sampled more quickly, thereby not allowing as much time for cross section fluctuations. In most other respects, sequential lobing is similar to the conical scan as far as error susceptibility. The sequential lobe technique can integrate more individual target position determinations for a given servo or filter bandwidth as a result of the higher scan or sample rate. It, therefore, would generally have slightly smaller errors.

Like the COSRO technique, sequential lobe has a receive only beam motion equivalent called LORO (Lobe On Receive Only). As in the case for COSRO, LORO is generally less vulnerable to deliberate deceptive interference and has a slightly larger gain. The larger gain of the COSRO and LORO techniques over the squinted transmit pattern type results from the target being located along the high gain centerline of the transmit pattern.

5.3 Monopulse Radar

The monopulse derives its name from the fact that a position determination can be made on the basis of a single pulse. Though actual implementation is generally more complex with a monopulse radar than with the conical scan or sequential lobe radar, monopulse may be envisioned as the ultimate end to the trend set by sequential lobe techniques. The monopulse transmits a single beam, called the transmit pattern, which is concentric with the antenna boresight and LOS to the target. Typically, the relative signal strength is sampled in four squinted directions simultaneously using multiple receive channels. The signals from the multiple receive channels and corresponding directionally sensitive feeds are combined in various ways to form sum and difference receive patterns, and the relative strength in the various patterns indicates the angular error between the LOS and boresight. Depending on the method of implementation, the receive sum pattern may be the same as the transmit pattern or not. The monopulse technique may be implemented to utilize either amplitude or phase information. Phase comparison monopulse is a technique which uses an interferometer type of angle determination.

Just as a monopulse may be envisioned as the ultimate end to the trend established by sequential lobing in comparison to its conical scan cousin, so is the monopulse error susceptibility an end to that of the sequential lobe trend. Monopulse is generally better in terms of signal-to-noise errors, but the greatest improvement is in the almost total elimination of scintillation. Because independent angular measurement samples are taken on a single pulse basis, the monopulse technique is also less susceptible to time dependent deception jamming.

5.4 Track While Scan (TWS) Radar

There are many and varied definitions of TWS, but perhaps the most consistent is that wherein TWS is defined as a technique in which the antenna is not physically boresighted along the LOS to the target. Because of this, TWS systems can simultaneouly track multiple targets and perform surveillance functions. TWS systems are typically characterized by assymmetrical scans over the target. Whereas the previously discussed techniques employ a symmetrical beam pattern motion about the LOS to the target, the TWS typically scans from left to right, right to left, up or down, or diagonally. Another characteristic of TWS systems is that the target's pattern is stored electronically, whereas boresighted tracking systems generally define the target angular position as the direction in which the antenna is pointed. TWS systems almost always employ discrete data filters, whereas inertial boresight systems seldom do (at least not usually as part of the track loop).

Perhaps the two greatest disadvantages of TWS systems lie in their low data rates and relatively poor signal-to-noise characteristics. The low data rate results from the fact that the antenna is not always pointed at the target. It is, therefore, generally worse in terms of error susceptibility than each of the other techniques.

An exception to this general rule exists if the beam is electronically scanned where the inertia or momentum of a physical antenna does not limit data rate.

In comparison with the other tracking techniques, TWS systems are relatively more error prone in the following areas:

a. S/N Ratio - Less average power on target results in lower S/N ratio and greater noise caused error susceptibility.

b. Scintillation - Low data rate and assymetrical scan can cause more susceptibility to scintillation effects.

c. Glint - Relatively more susceptible due to sample time aperture and low data rate.

d. Multipath - Since, classically, TWS is employed to simultaneously perform surveillance and track functions, it is characterized by larger beamwidths and greater susceptibility to multipath induced errors.

e. Clutter - More susceptible for many reasons.

f. Instrumental and Ganularity - Almost always characterized by granularity errors associated with digital processing dynamic range, and in the case of electronic scanning techniques, by a beamstep granularity.

g. Track Filter/Servo Bandwidths - Requires longer integration time intervals with correspondingly narrower effective bandwidth to get acceptably smooth tracks. As a result, filtered target estimates lag actual target positions severely under maneuvering conditions.

SECTION 6
THEORETICAL MATCALS ACCURACY AS A FUNCTION OF RANGE

6.1 Definition and Assumption

The AN/TPN-22 accuracy analysis undertaken at Georgia Tech is a statistical analysis based on the theoretical properties of tracking radar systems. The term statistical indicates that the exact response of the radar to a set of conditions is not modeled. Rather, a measure of the radar's errors are calculated. Those errors may be divided into two parts: average, or offset errors, and fluctuating errors. The Georgia Tech analysis assumed that the average error, or the offset error, was zero. Therefore, only the fluctuating portion of the error signals were studied. Since this analysis was statistical, spectral properties of the errors were not investigated. This may be a good area for future work.

The analysis tool used at Georgia Tech is a computer analysis program first devloped under the acronym STREAM, standing for Statistical Tracking Radar Error Analysis Model. The program is basically an automated error analysis based on the procedure and formulas presented in the Handbook of Radar Measurement by D. K. Barton and H. R. Ward (Prentice Hall, 1969), and extensively modified and extended at Georgia Tech. The analysis routine is presently equipped to evaluate conical scan, sequential lobing, monopulse, track-while-scan, and edge track techniques.[7] Several basic assumptions have been made which make the analysis manageable while keeping it as universal as practicable. The assumptions include:

a. The average error is zero. This implies that the radar system has a fairly good estimate of the target position and also that the radar beam is always directed exactly toward the target. Errors associated with pointing accuracy are not included in the analysis. This assumption is not limiting in real world applications since, if it is violated, the radar could not track the target because the errors would be too large.

b. Statistically uncorrelated errors are assumed; this essentially means that the effects of one error source will not influence errors due to another source. This does not imply, however, that two statistically uncorrelated errors may not be caused by the same phenomenon, for example, scintillation and glint. The error equations have been formulated so as to provide this implementation.

c. The errors are independent from point to point along the aircraft glideslope. The analysis program flies the target along a predetermined path. The tracking errors are then computed at discrete locations along that path, assuming that previous errors have no effect on future errors. This technique provides a better model of the real world in general and more applicable results specifically.

Results of this error analysis identify the one sigma (1σ) errors as a function of range. The standard deviation (sigma) of the error distribution is a mathematical measure of how concentrated the error is about the mean (in this case, zero). For the Gaussian, or Normal, probability distribution typical of tracking radar errors, 68% of the position measurements will be within plus or minus ($\pm$) one sigma of the true target position; 95% will be within $\pm 2\sigma$; and 99.7% will be within $\pm 3\sigma$ of the true target position.

6.2 Analysis Procedure

Since edge tracking is a new concept, the determination of the theoretial edge tracking errors required development of a new analysis procedure. Of the classical tracking techniques outlined previously, edge tracking most closely resembles a track-while-scan concept. When the AN/TPN-22 radar system is unable to resolve the scatterers near the edge of the target from the remainder of the target, then, in fact, the radar tracking errors will be the same as those of a conventional TWS system. These TWS results provide an upper bound on the system errors; that is, the edge track technique will be at least as good as an equivalent TWS radar system.

A lower error bound on the system errors will be determined if perfect edge track performance is assumed. "Perfect" performance may be defined as the radar's resolving of the outermost scattering centers from the rest of the target. In this case the scintillation and glint errors will be reduced, since they are primarily multiple scatterer phenomena. Scintillation caused by frequency scanning will not be reduced, however, because this error is associated with both single and multiple scatterers. The other tracking errors will remain as predicted by the TWS formulas. Based on the above, one would expect that an edge track system would yield better performance than a similar TWS system in the medium and short range regions and equivalent accuracies at long range.

The actual edge track error statistics will lie between the upper and lower limits established above. The transition from one type of error statistics to the other type will be gradual, rather than an abrupt change. The net edge track errors during this transition may be calculated from the normal TWS errors, the edge track errors, and the probability that the radar is actually edge tracking. Note that this probability as well as the error sigmas (both edge track and normal TWS) are functions of range.

A two scatterer analysis technique was used to determine the probability of edge tracking. It is important to recognize that a two scatterer analysis does <u>not</u> indicate a two scatterer model of the target. No attempt has been made to model the actual target aircraft. The two scatterers used in the analysis may or may not be associated with certain physical scattering centers on the aircraft. It is most likely that both scatterers represent combinations of several scattering centers

The assumed position of the two scatterers relative to each other depends on which target edge positon is being determined. When the radar is locating a horizontal (left or right wingtip) edge, the two scatterers have the same elevation and are separated in azimuth (horizontally) by a constant distance. (Note that this is a constant distance at the target; the apparent angular separation at the radar changes.) Similarly, when the radar is determining a vertical (top or bottom) edge, the scatterers are in the same azimuth plane and are separated in elevation by a constant distance at the target. When finding the left edge, the radar steps the beam from left to right and attempts to detect the composite target returns at the -12 dB point of the one-way antenna power pattern. The composite target signal, for analysis purposes, is composed of returns from the two separate scatterers. The radar system attempts to determine the position of the outer (in the above case, the left) scatterer. This goal is not always realized because, as noted above, the radar must work with the composite target signal. The ratio of the return signal strength of the outer scatterer to the return signal strength of the inner scatterer determines the probability of successfully edge tracking.

Two factors determine the return signal strength from a scatterer: 1) the radar cross-section of the scattering center and 2) the antenna gain in the direction of the scattering center. For this analysis, a relative radar cross-section of the outer to the inner scatterer and the separation between scatterers are input parameters to the computer program. The antenna gain of the outer scatterer is fixed at -12 dB relative to beam center. The antenna gain of the inner scatterer is computed assuming a (sin x)/x type antenna pattern with the sidelobes reduced to match the actual average sidelobe level. The final result is a probability of edge tracking function, as presented in Figure 6-1.

Several things should be noted about Figure 6-1.

a. For high signal strength ratios (i.e., greater than 10), the probability of edge track is approximately unity. This is the desired case: the outer scatterer is being detected.

b. For low signal strength ratios (i.e., less than 0.1), the probability of edge track is also approximately unity. (Reciprocal signal strength ratios will have equal probabilities). This is an undesired situation: the inner scatterer is being tracked. Note that for both these cases, the fluctuating component of the tracking error, as characterized by the standard deviation, or sigma, will be equal. For the second situation, however, there will be an offset error equal to the scatterer separation.

c. When the relative signal strength is unity, indicating equal return signal strength from the two scatterers, the probability of edge track will be zero. In this case, the radar will be subject to full glint and scintillation errors, as would a conventional TWS system.

The shape of the curve between the probability points described above is determined by the probability density function of the composite signal amplitude from the two scatterers and is composed of two multiplicative terms. The first term is of the form:

$$1 - \frac{1}{SSR},$$

where SSR is the Signal Strength Ratio. This term is proportional to one minus the spread, or standard deviation, of the composite signal distribution around the expected, or average, composite signal amplitude. The second term modifies the gross behavior as determined by the first term and accounts for the skew in the probability distribution when the SSR is close to unity. The second term is of the form:

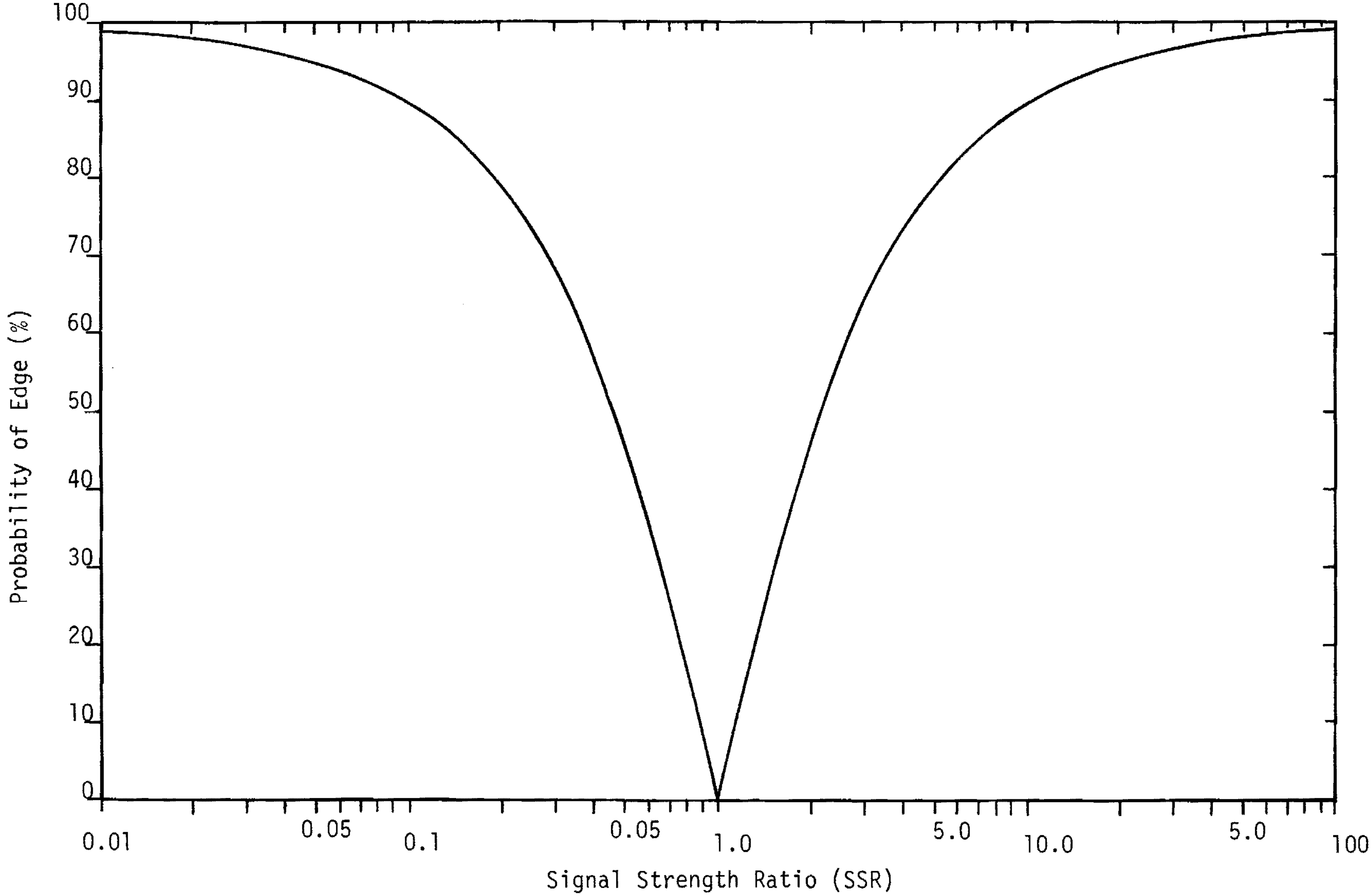

Figure 6-1. Probability of Edge vs. Signal Strength Ratio.

$$1 - \frac{0.3}{SSR^2}$$

The final step in determining the edge track errors is to use the probability function shown in Figure 6-1 to determine the appropriate mixing of the error bounds to yield the desired result.

In summary, a four step procedure is used to compute the theoretical edge track errors:

a. Determine the tracking errors associated with an equivalent TWS radar system.

b. Determine the tracking errors of a perfect edge tracking radar system.

c. Calculate the probability of edge tracking.

d. Mix the two error bounds determined in a. and b. using the probability function found in c.

Two potential error sources not included in the analysis will affect the probability of edge track calculation. One error source is caused by target amplitude fluctuations during a single position determination (i.e., during a cross-scan). These fluctuations will cause the composite target return to not be detected at the -12 dB point. Three causes of this error include misadjustment of the Gated Automatic Gain Control (GAGC), target signal fluctuation during the position measurement, and induced scintillation due to frequency scanning the beam in elevation. The third cause of error is included in the analysis, while the second should cause only small errors. The second potential error source omitted has only second order effects, and its omission should affect the results only minimally. Recall that in the calculation of the relative signal strength, the antenna gain of the outer scatterer was fixed at -12 dB relative to maximum gain. Actually, it is the composite target return signal which is detected at the -12 dB point of the antenna beam. This has the effect of increasing the antenna gain function for both the inner and outer scatterers. Thus the relative antenna gain between the scatterers is affected only slightly.

6.3 Individual Error Sources of the Edge Track Method

6.3.1 Signal-to-Noise Ratio

Effects of signal-to-noise ratio on edge tracking are identical to those on a conventional TWS system. The form of the error equation is

$$\sigma_{SNR} = K\,\Theta \sqrt{\frac{\beta}{SNR}},$$

where:

K = constant

Θ = antenna beamwidth

β = track filter bandwidth

SNR = signal-to-noise energy ratio.

Figures 6-2 and 6-3 present the tracking errors of the AN/TPN-22 radar system for the baseline scenario which represents the nominal radar and aircraft configuration. The input data for this scenario is presented in Table 6-1. As can be seen in Figures 6-2 and 6-3, the contribution of signal-to-noise ratio errors becomes significant only at long ranges, where the signal strength is low. It may thus be concluded that the radar is well matched to its requirements from this standpoint.

6.3.2 Instrumental/Granularity

The error term included in the AN/TPN-22 analysis from this source is the beam step granulation. The 0.04 degree beam step size causes a one sigma error of .016 degree, or 0.285 mrad per measurement.

This value is obtained by assuming a uniform probability distribution over the 0.04 degree granularity interval. The sigma associated with this distribution is given by

$$\sigma = \frac{0.04^{\circ}}{\sqrt{12}}$$

This is the error associated with determination of one edge position. The error associated with the other edge position will have the same error distribution and the two errors will be uncorrelated, because during edge determination the beam centers are separated by many multiples of 0.04 degree. Thus, the overall error in centroid estimation will be equal to the single edge error multiplied by the square root of two.

A basic assumption here is that the other error types mentioned in Section 4.2 are much smaller than the beam step granulation. For a well designed radar system, this will be the case. This error has been lumped with scintillation in the computer error program for simplicity. The above error sigma will be reduced by the number of position determinations integrated in the tracking filter. For a filter bandwidth

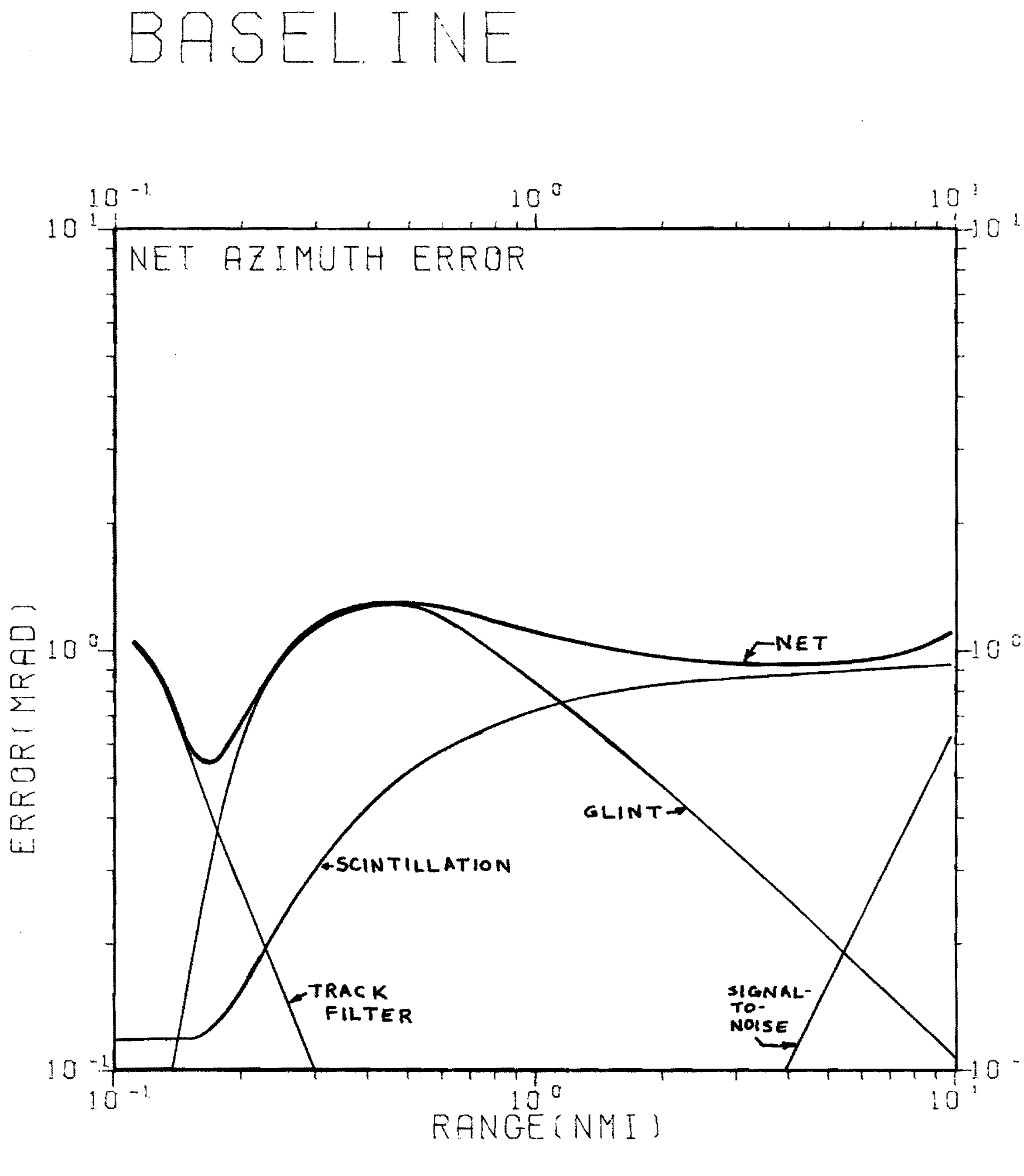

Figure 6-2. Azimuth Tracking Errors for the Baseline Case.

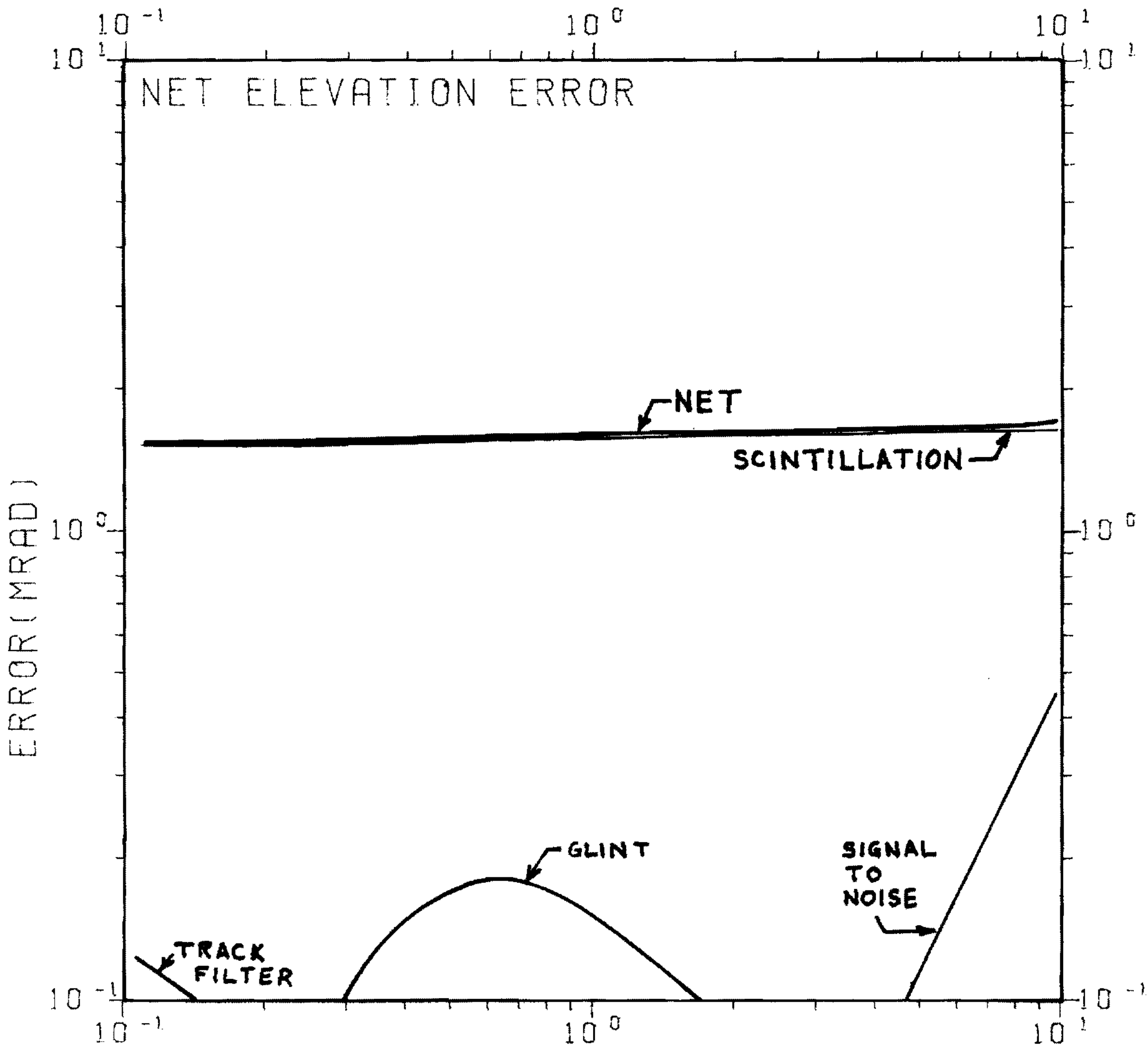

Figure 6-3. Elevation Tracking Errors for the Baseline Case.

Table 6-1

Data for Scenario Baseline

Radar parameter dimensions in parentheses, no parenthesis for dimensional parameter.

Peak Power (kw)	120.0
Antenna Gain (db)	39.0
Azimuth 3dB BW (deg)	1.0
Elevation 3dB BW (deg)	.7
Pulsewidth (microsec)	.25
Wavelength (cm)	3.20
Thermal Factor (watts/MHz)	.4E-14
IF Bandwidth (MHz)	6.0
Transmit Line Loss (dB)	1.5
Receive Line Loss (dB)	3.3
Pattern Loss (dB)	3.2
IF Mismatch Loss (dB)	0.0
Crossover Loss (dB)	12.0
Average Sidelobe (dB)	26.0
Angle Track Constant	0.00
PRF (PPS)	6000.0
Number of pulses during dwell time	1.0
Range Track Constant	2.00
Collapsing Loss (dB)	0.0
Servo Angular Accelleration Constant (SE -2)	111.0
Servo Angular Velocity Constant (SE -1)	500.0
Servo Range Acceleration Constant (SE -2)	40.0
Antenna Height (feet)	6.0
Frequency (MHz)	9200.0
Elevation Type	4
Azimuth Type	4
IPOL	1
Noise Figure (dB)	3.5
Frame Rate (Hz)	10.0
Range Servo Bandwidth (Hz)	7.0
Angle Servo Bandwidth (Hz)	6.7
Number Independent Tracks/Dimensions	2.0
Beamstep Granulation (deg)	.0400

Target parameters dimensions in parentheses, no parenthesis for dimensionless parameter.

Width (meters)	10.0
Lenght (meters)	10.0
Height (meters)	2.0
Velocity (knots)	150.0
Decorrelation Time (millisec)	150.0
Cross Section (square meters)	10.0

Table 6-1

Data for Scenario Baseline

(Continued)

OBJ Power Spectral Density (watts/MHz)	0.0
OBJ Max Gain (dB)	0.0
Scatterer Separation (feet)	6.0
Relative RCS of the Two Scatterers (azimuth) (dB)	0.00
Relative RCS of the Two Scatterers (elevation) (dB)	0.00

Scenario parameter dimensions in parentheses, no parenthesis for dimensionless parameter

Minimum Range (nm)	.11
Maximum Range (nm)	10.00
Multiple Range and Height Increment	1.10000
Target Height at RMIN (feet)	42.0
Target Height at Zero Range (feet)	1.10000
Profile Offset (nm)	.0450
Tajectory Type	0

Clutter parameter dimensions in parenthesis, no parenthesis for dimensionless parameter.

RMS Waveheight (feet)	10.0
Decorrelation Distance (feet)	10.0
Wind Velocity (knots)	10.0
Backscatter Coefficient (dB)	30.0
Clutter Improvement Factor	50.0

Rain parameter dimensions in parenthesis, no parenthesis for dimensionless parameter.

Rain Fall Rate (mm/hr)	0.0
Absorption Coefficient (dB/km)	0.000
Backscatter Coefficient (1/meter)	0.
Backscatter Improvement Factor (dB)	50.0

of 6.7 Hz and a position determination rate of 10 Hz, an error reduction of approximately 18 percent results.

6.3.3 Track Filter

Track filter effects will be the same for edge tracking as for any other tracking method, as discussed in Section 4.3. Figures 6-2 and 6-3 illustrate those errors for the baseline case. Section 7 discusses several methods of reducing the track filter lag, including increasing the filter bandwidth, increasing the sampling rate, and shifting the origin of the coordinate system.

6.3.4 Scintillation and Glint Effect

As noted earlier, scintillation and glint errors will be reduced for a perfect edge track system as compared with a equivalent TWS system. The actual error will be a function of these two systems' error bounds and the probability of edge tracking. Figure 6-4 presents the probability of edge tracking for the baseline case considered for MATCALS.

Significantly high probabilities are achieved only at ranges less than about one mile, because it is only at short ranges that the signal strength ratio is much greater than unity. As the two scatterers have equal cross-sections in the baseline case, the difference in received signal strength is due entirely to the different antenna gains of the two returns. For the assumed (sin x)/x structure in the main lobe, this difference is sufficiently large only at close ranges. One should note, however, that by detecting at a point on the antenna beam which has greater slope than the -12 dB point of the (sin x)/x curve, better edge tracking performance can be achieved. This greater beamshape slope may be obtained through detecting at a different location on the (sin x)/x beam, or by using a differently shaped beam. This approach is discussed more fully in Section 7.

In addition to the classical scintillation errors outlined above, the AN/TPN-22 is subject to an induced scintillation error in the elevation plane due to the frequency shift technique employed to scan the radar beam in elevation. This error is due to the target's radar cross-section changing as a function of frequency. The change may be attributed to two sources. First, the cross-section of each individual scatterer varies as a function of frequency. Secondly, the returns from each scattering center will combine differently as the frequency changes, because their spacing relative to a wavelength changes. Frequency scintillation is analyzed in a manner very similar to time scintillation. For either effect a decorrelation time, or

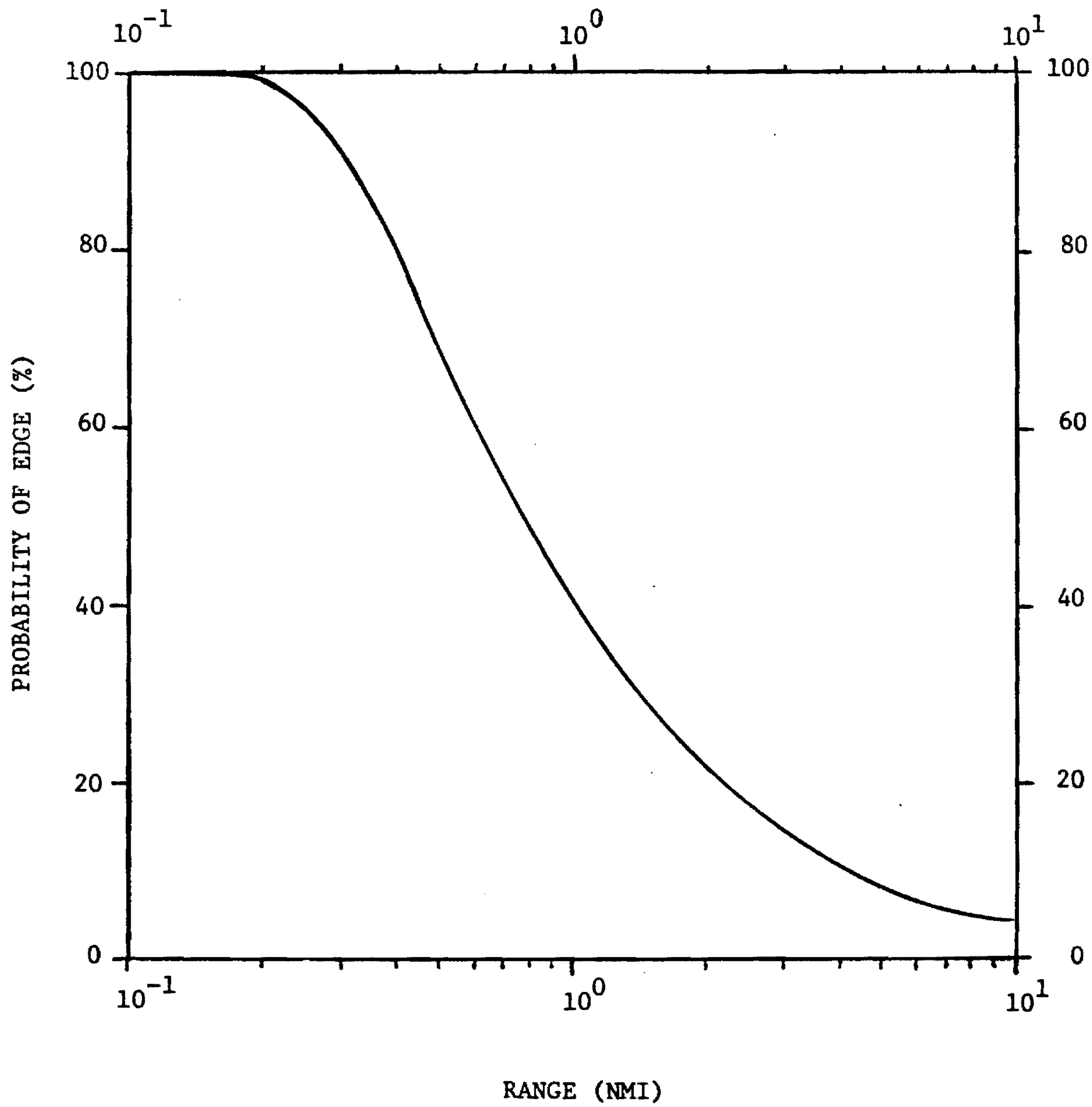

Figure 6-4. Probability of Edge Track Versus Range, Baseline Case.

frequency shift required for decorrelation, is determined based on target size and relative motion of its scattering centers. The error sigma is then calculated as a function of this decorrelation parameter. This effect is demonstrated in Section 6.4.

Figures 6-2 and 6-3 show how the scintillation and glint errors vary as a function of range for the baseline case. The effect of increasing the probability of edge tracking is readily apparent in the azimuth scintillation error and both azimuth and elevation glint errors. The elevation scintillation error is virtually constant with range, however, because of the dominant effect of the induced frequency scintillation, which applies to both normal and edge track statistics.

6.3.5 Clutter Effects

Errors due to clutter were determined to be minimal in the scenario considered, since the main beam never intersects the ground for a 3.5° glideslope flight path. Therefore, the ground clutter return is at a very low amplitude compared with the desired target echo, and the error is minimal. If the main beam does ever intersect the ground, then the clutter error may become significant. Figure 6-5 plots the altitude below which the the target aircraft must fly in order for the main beam to intersect the ground at the -12 dB point (since the target is detected at the -12 dB point, this is appropriate). This calculation assumes flat terrain. Volume clutter, such as rainfall, was not considered in the analysis, but will be addressed in future efforts.

6.3.6 Multipath Effects

Multipath should not be a major error source for the same reason that clutter errors are not significant. That is because the target return signal should be much larger than any interfering multipath signals. If, however, the aircraft altitude drops below that shown in Figure 6-5, the multipath error contribution will rise significantly.

6.3.7 Electromagnetic Interference Effects

Electromagnetic interference erors were not considered in this analysis, because there should be no significant jamming activity in the area where the AN/TPN-22 is deployed. Interference from other AN/TPN-22 radars and/or other radars in the area was also assumed to be negligible.

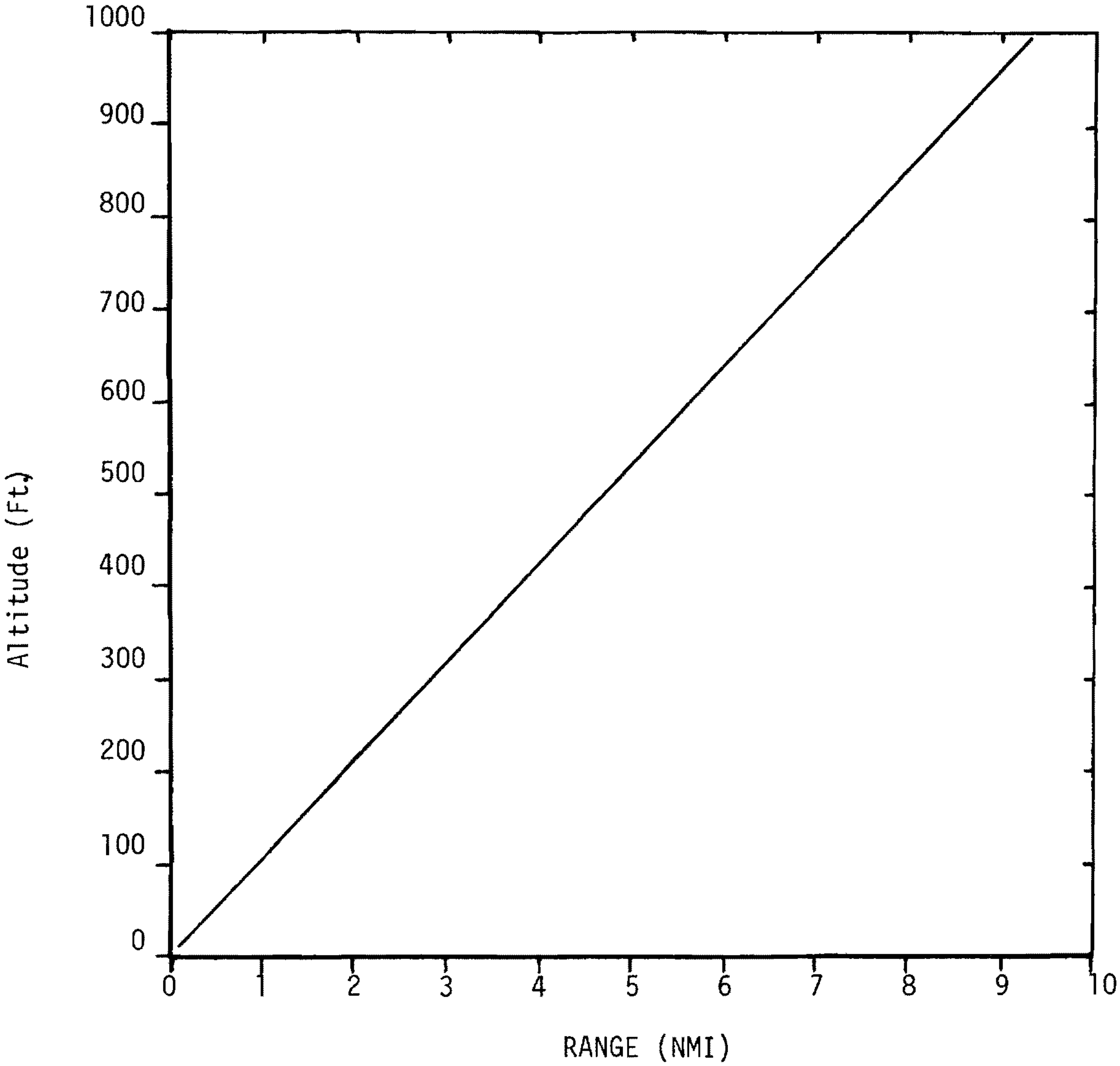

Figure 6-5. Altitude Below Which an Aircraft Must Fly for the TPN-22 Mainbeam to Intersect the Ground.

6.4 Analysis Results

6.4.1 Baseline Case

Figures 6-2 and 6-3 presented the azimuth and elevation errors for the baseline case as determined theoretically. For the azimuth tracking error, no one error source dominates. At long ranges, scintillation and signal-to-noise effects cause the largest tracking errors. From about 0.2 mile to one mile in range, glint errors predominate, and for very close ranges the track filter lag is the largest. The net elevation error, on the other hand, is completely dominated by the scintillation error, of which, it will be shown, the largest component is the induced scintillation due to frequency scanning.

As noted earlier, the analysis procedure calculated errors for a perfect edge track and for an equivalent TWS system. Figure 6-6 presents these two limiting cases for the azimuth error. Note that each of these cases shows the classical shape associated with tracking radar error, but that the edge track technique has a much lower net error over most of the range of the radar. The total error is derived from these two sources and the probability of edge track, which was presented as Figure 6-4. Note that the probability of edge track becomes large only for ranges of less than about one mile. This is also apparent by noting that Figure 6-2 differs significantly from Figure 6-6 only at close range. Differences between the elevation error limiting cases are much less dramatic than for azimuth, as is illustrated in Figure 6-7. The main difference between them may be attributed to the glint error associated with the equivalent TWS system.

Figure 6-8 illustrates how the induced frequency scintillation dominates the net elevation error by presenting the net elevation tracking error without frequency scintillation. It is clear from Figure 6-8 that any attempts to reduce elevation errors must address this frequency dependent effect (this is discussed further in the following section). The frequency scintillation analysis made certain assumptions about the frequency decorrelation of the aircraft echo signal. The method used for the analysis has been used successfully in the past and is based on matching measured data. Because the frequency scintillation term is so important, it would be worthwhile to refine the model in the future by making use of measured radar cross-section data for the aircraft under consideration.

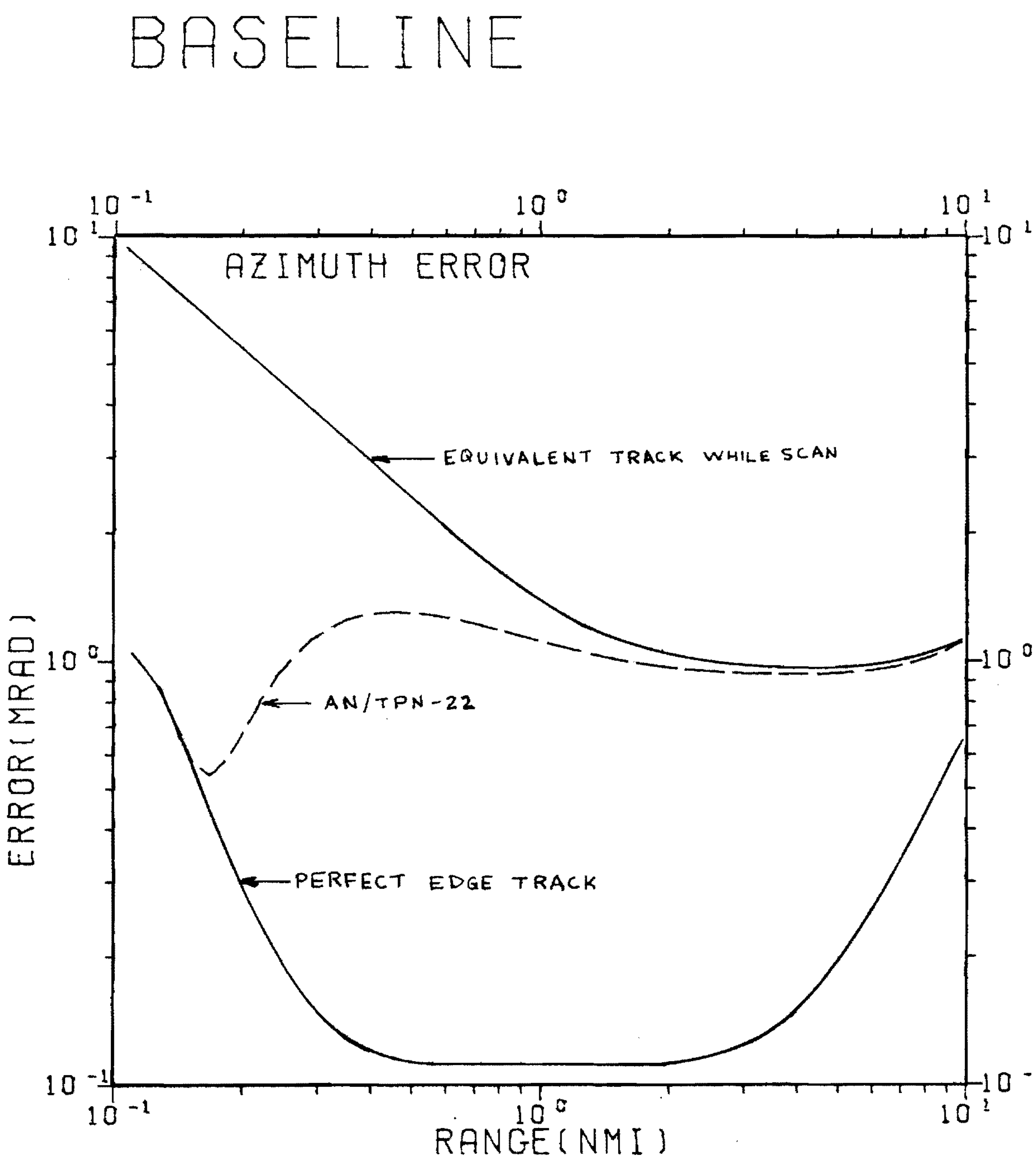

Figure 6-6. Baseline Azimuth Tracking Errors for the TPN-22, the Perfect Edge Track, and the Equivalent Track While Scan Radars.

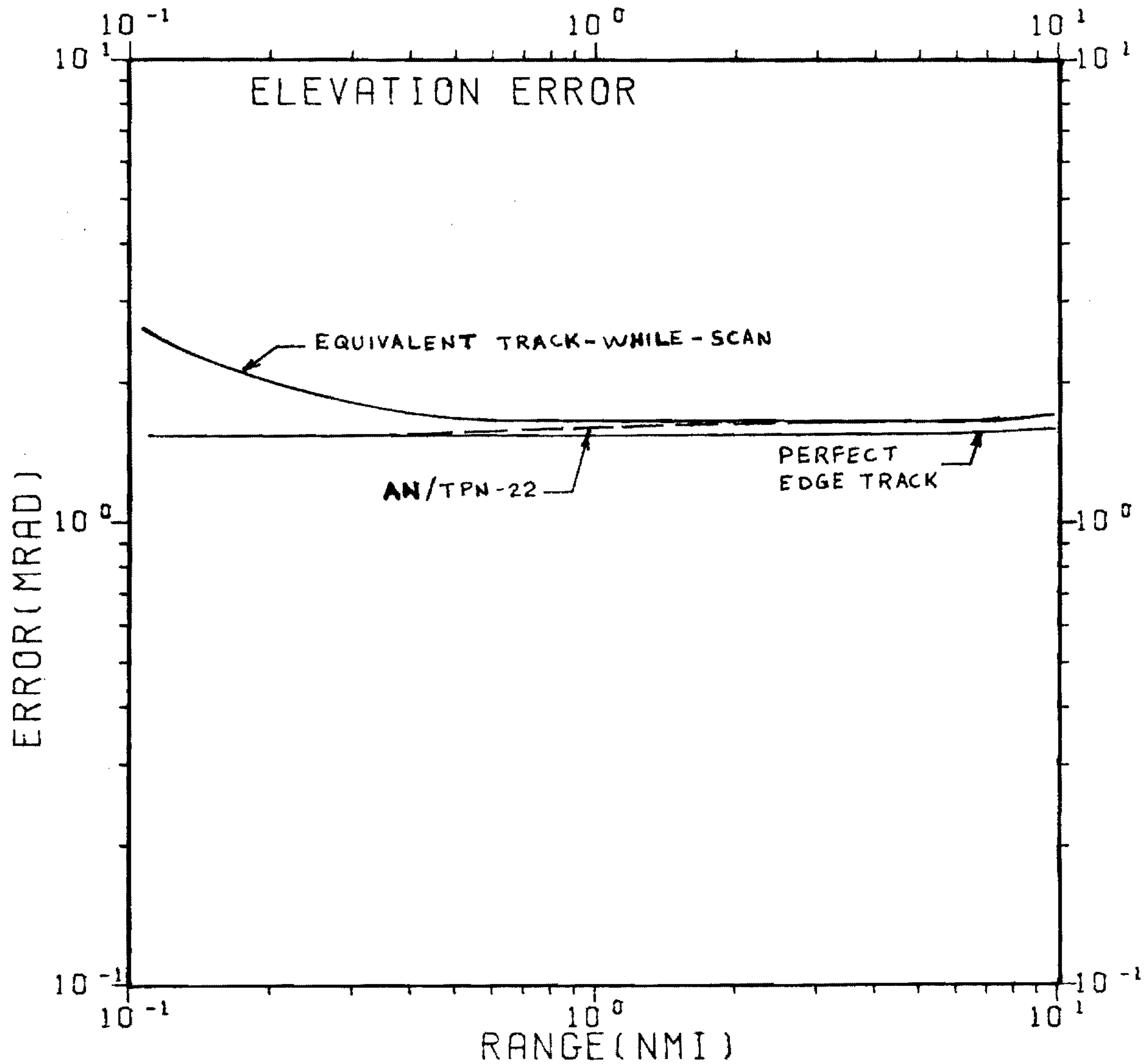

Figure 6-7. Baseline Elevation Tracking Errors for the TPN-22, the Perfect Edge Track, and the Equivalent Track-While-Scan Radars.

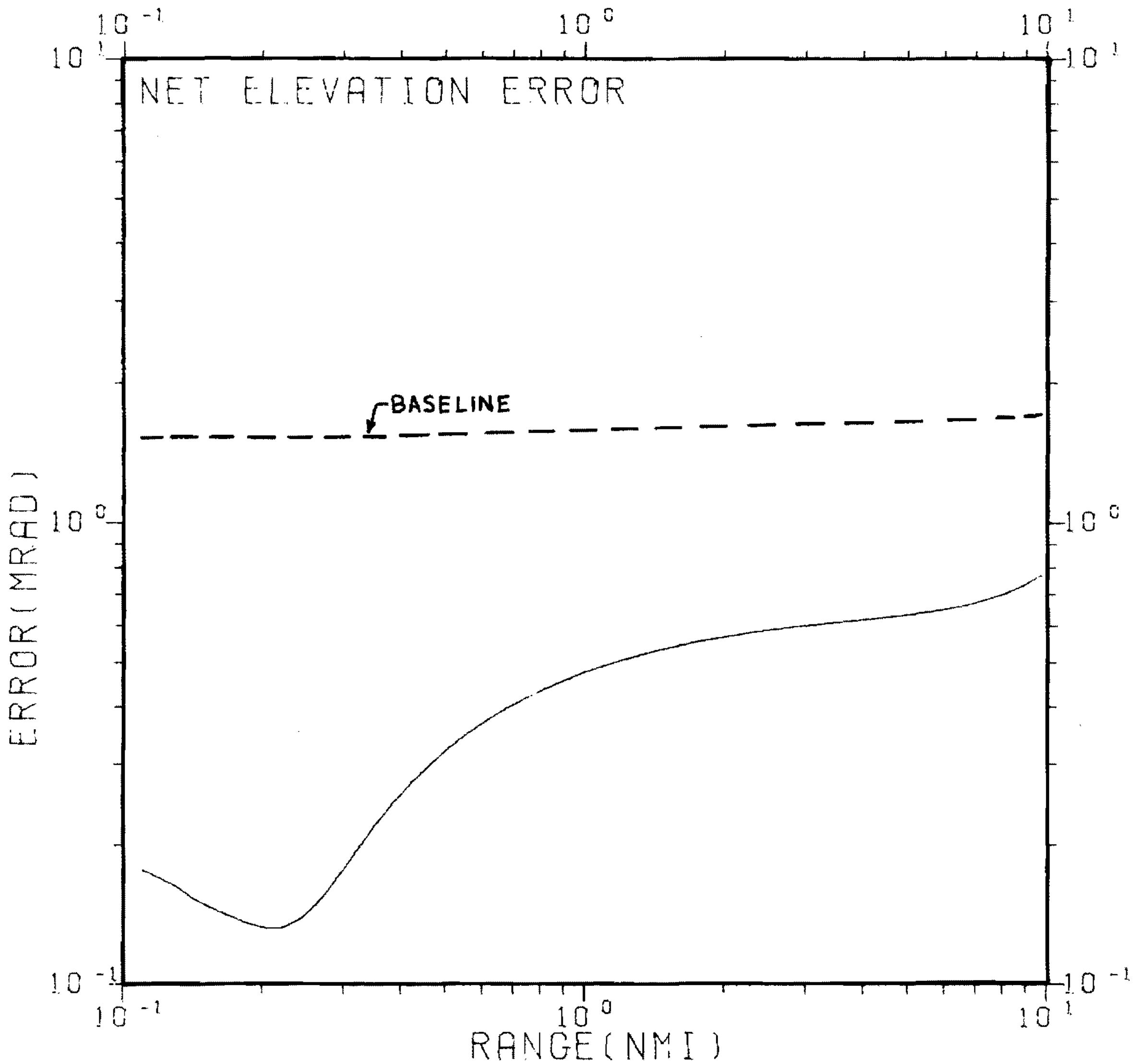

Figure 6-8. Net Elevation Tracking Error Without Frequency Induced Scintillation, Compared with Baseline Case.

6.4.2 Analysis Sensivity

The results predicted by this analysis are sensitive to the method chosen for the analysis and to the parameters input to the computer model. By varying certain of those input parameters, confidence intervals may be established on the predicted errors. That is, by allowing the input parameters to assume values over their entire range, the expected output sensitivity may be determined for that parameter.

Determination of the perfect edge track and equivalent TWS errors is straightforward. The correct method of mixing these two relevant error bounds, however, is less obvious. Thus, in order to ascertain the analysis sensitivity it is necessary and sufficient to determine the tracking error sensitivity to the probability of edge calculation.

Three items determine the probability of edge: (1) the antenna beamshape, (2) the assumed relative radar cross-sections of the two scatters, and (3) the scatterer separation. Items (2) and (3) are input parameters to the model, while the antenna pattern has been assumed to have a $\frac{\sin x}{x}$ beamshape. Effects of changing beamshape are discussed in Section 7 and will not be considered further here. The baseline analysis assumed equal strength scatterers with a separation of six feet for all ranges. This separation was selected from consideration of the physical size of the F-4J aircraft and the expected location of the actual physical scatterers. As the plane approaches the runway, both of these appropriate scatterer strengths and their separation will vary in a somewhat random manner. (These effects are not actually random but could, in principle, be determined by physical laws. In appearance, however, they appear random and cannot be accurately predicted. Thus, the scatterers actions may be treated as random.)

Table 6-2 lists the parameter sets considered for the sensitivity study. (A positive Relative Strength indicates the desired, or outer, scatterer is stronger than the undesired, or inner, scatterer.) Figure 6-9 illustrates how the net azimuth error changes as a function of relative scatterer strength for a constant six foot scatterer separation. The radar range may be divided into three regions, in which the tracking errors have different character. At very close range, within 0.1 mile, each parameter set shows approximately the same tracking error, which is determined mainly by the tracking filter lag. This occurs in this region because the probability of tracking the correct edge is very high: the antenna pattern effectively discriminates against the undesired signal from the second scatterer. Between the

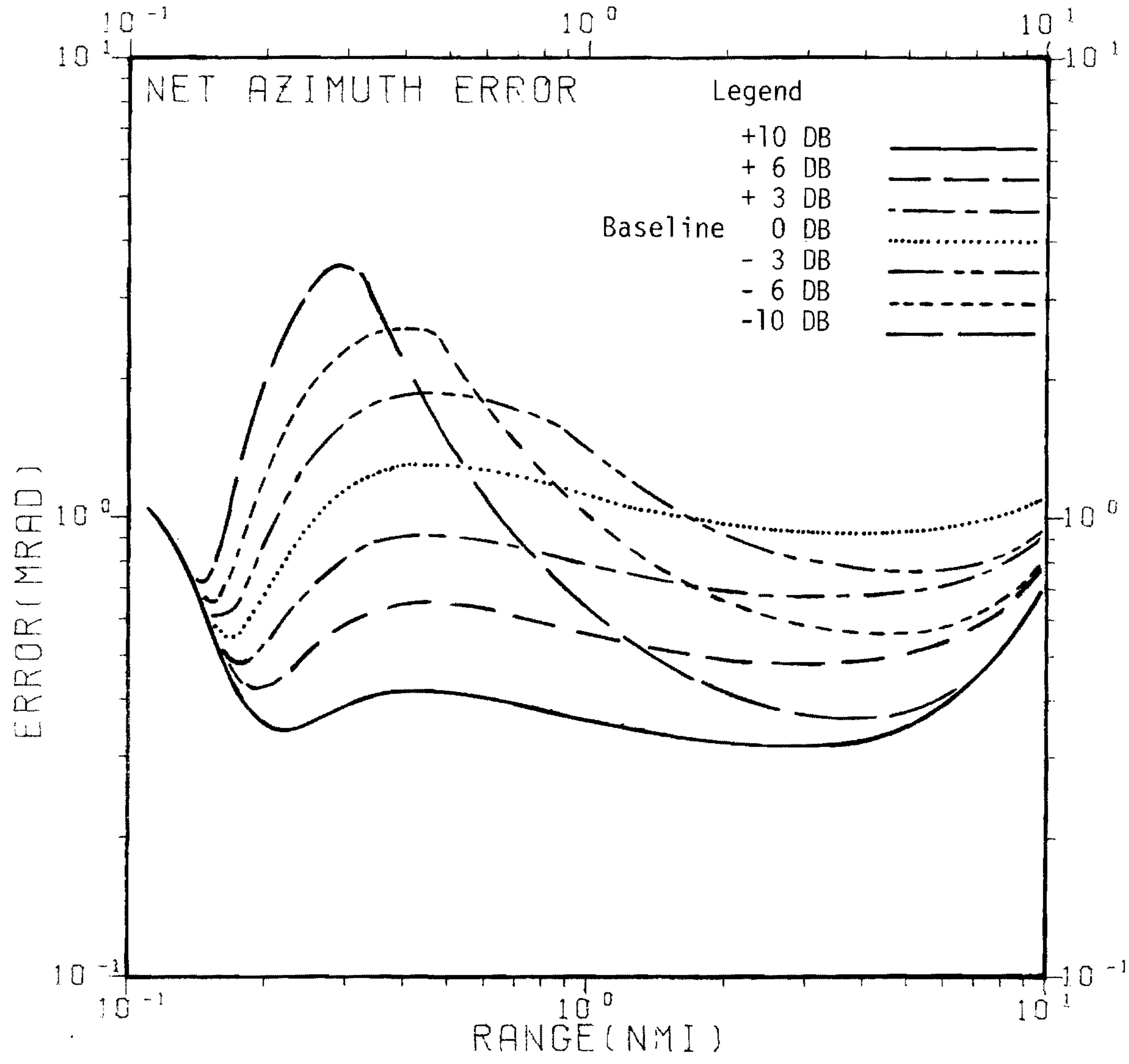

Figure 6-9. Net Azimuth Tracking Error as a Function of Relative Scatterer Strength, for a Constant Six Foot Scatterer Separation.

ranges of 0.2 mile and approximately 1.0 mile, the different parameter sets cause widely varying results. In this region, the probability of edge track is changing most rapidly. For non-negative relative scatterer strengths, the probability of edge track monotonically decreases with increasing range. Therefore, the tracking error curves are all similar, and this error decreases with increasing relative radar cross-section. Negative relative scatterer strengths, however, result in more complicated error behavior. The probability of edge, with increasing range, falls rapidly to zero, at which point the signal strength ratio (SSR) is unity. This point occurs at .3 mile for -10 dB relative strength, 0.5 mile for -6 dB, and 0.9 mile for the -3 dB case. At ranges greater than these points, the radar begins to track the wrong scatterer, causing a six foot shift in the estimated target centroid, but the probability of edge rises again as the signal strength ratio drops well below unity. Beyond one mile, the tracking errors for these parameter sets are again close together. It is interesting to note that at a 10 mile range the tracking error depends on the absolute value of the relative scatterer strength. This is due to the fact that the antenna gains at the two scatterer locations are virtually the same. In other words, the angular separation between these locations becomes very small compared with the antenna beamwidth.

Table 6-2
Sensitivity Study Runs

Scatterer Separation (ft)	Relative Strength (dB)	Figure
6	+3	6-9, 10
6	-3	6-9, 10
6	+6	6-9, 10
6	-6	6-9, 10
6	+10	6-9, 10
6	-10	6-9, 10
12	0	6-11, 12
12	+16	6-11, 12
12	-16	6-11, 12
24	0	6-11, 12

Figure 6-10 shows the elevation tracking error for the same conditions as Figure 6-9. In this case, however, the differences are not as dramatic, being very small in comparison. As noted earlier, these tracking errors are dominated by the frequency induced scintillation error, which is common to both the edge track and TWS type systems. Curves for the +3 dB and +6 dB cases are identical to the +10 dB case which is illustrated.

The next Figure, 6-11, illustrates the net azimuth tracking errors for a different scatterer separation and three values of relative scatterer cross-section. The results are similar to those presented in Figure 6-9, except that the first region, where the probability of edge track is high, extends to about 0.3 mile. Reasons for the shape of the curves are the same as in the previous figure. It is important to note, however, the much improved tracking performance in the region from 0.15 to over 0.5 mile, where tracking accuracy is the most critical. This is again due to an increased probability of edge track due to the greater scatterer separation. A method of achieving this improvement is discussed in Section 7. The elevation error results depicted in Figure 6-12 show even less variation than those of Figure 6-10. The overall limits of the variation in the net azimuth error are illustrated in Figure 6-13. The inner curve is a median value around which the actual error will fluctuate. Due to slight changes between landing scenarios and between aircraft, the errors associated with each landing will be different. It is highly probable that the one sigma tracking error for each landing will fall within the illustrated bounds at all ranges. Further, it is a virtual certainty that for a large number of landings, <u>all</u> values of tracking error within those limits will be experienced. The large variation in the expected error (approximately 20:1 at 0.3 mile) will be impossible to predict accurately and very difficult to compensate for. At the largest error values, automatic landings may not be possible. For these reasons, it appears highly desirable to improve the performance of the AN/TPN-22 at ranges from one mile to touchdown. A potentially effective method for accomplishing this is discussed in Section 7. Net elevation errors have been seen to be only minimally affected by the expected variation in the targets scattering properties.

6.4.3 Range Accuracy

The theoretical range tracking performance of the AN/TPN-22 radar system was also calculated as part of the analysis procedure. The one sigma error for the

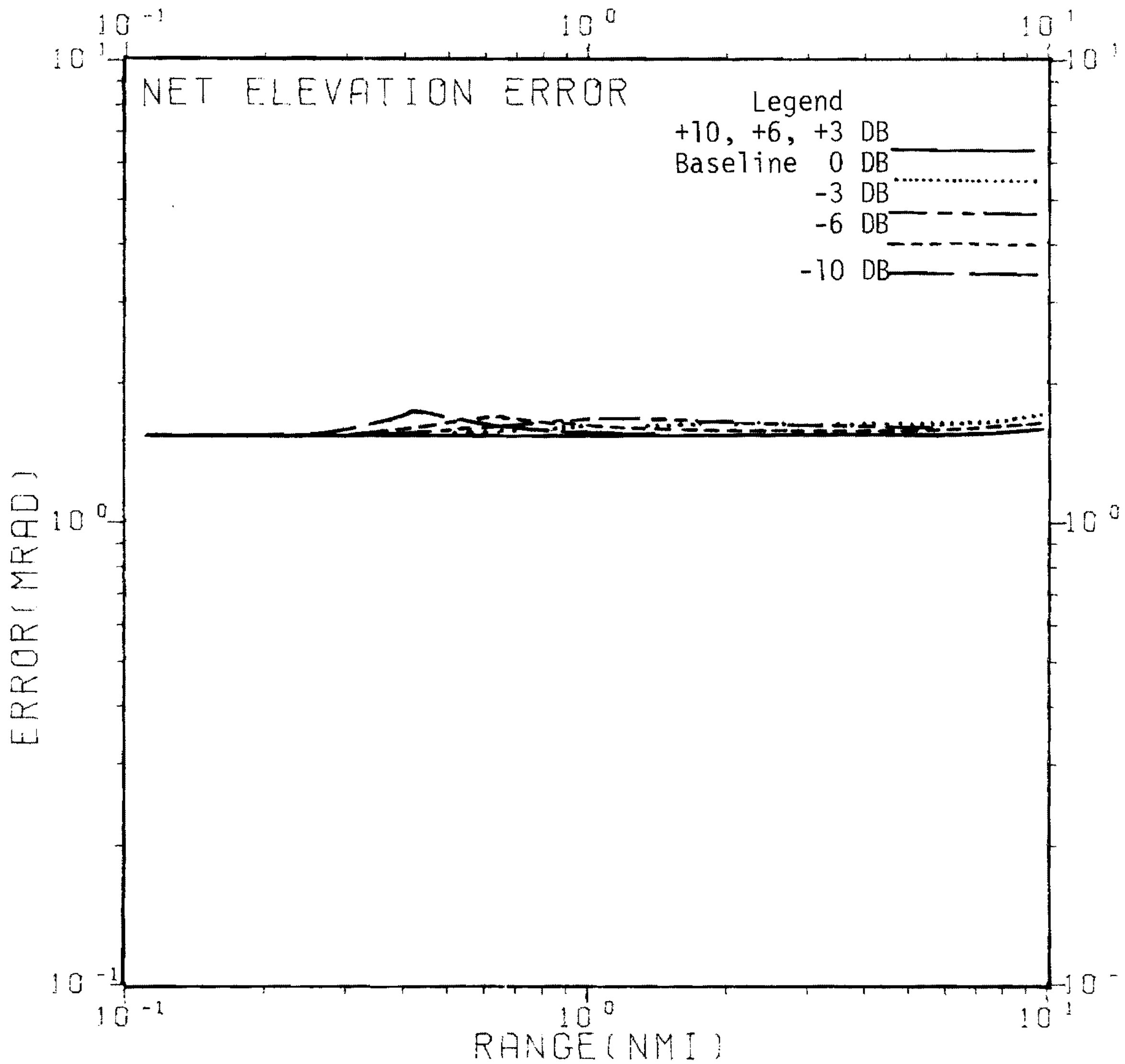

Figure 6-10. Net Elevation Tracking Error as a Function of Relative Scatterer Strength, for a Constant Six Foot Scatterer Separation.

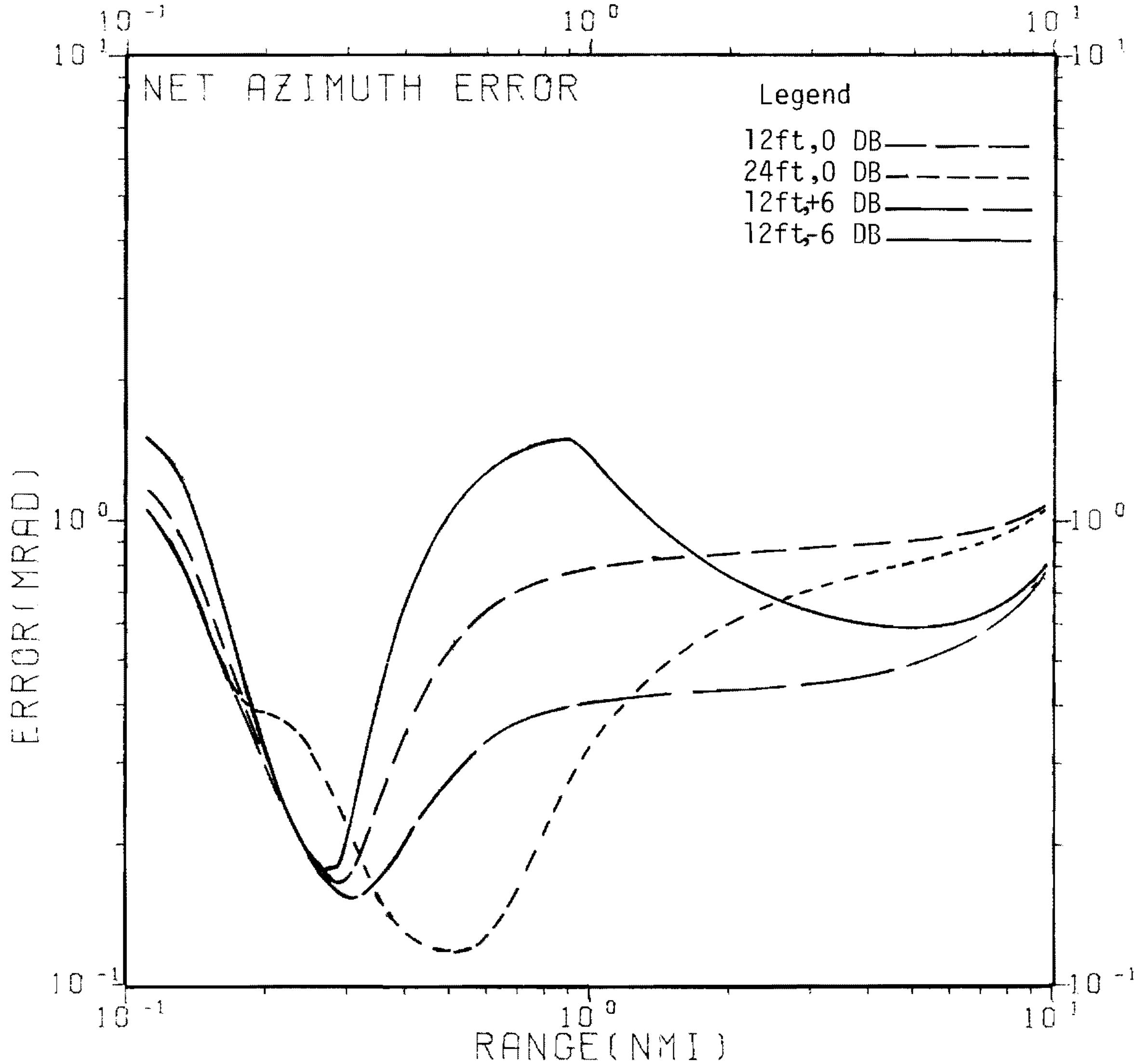

Figure 6-11. Net Azimuth Tracking Error as a Function of Scatterer Separation and Relative Scatterer Strength.

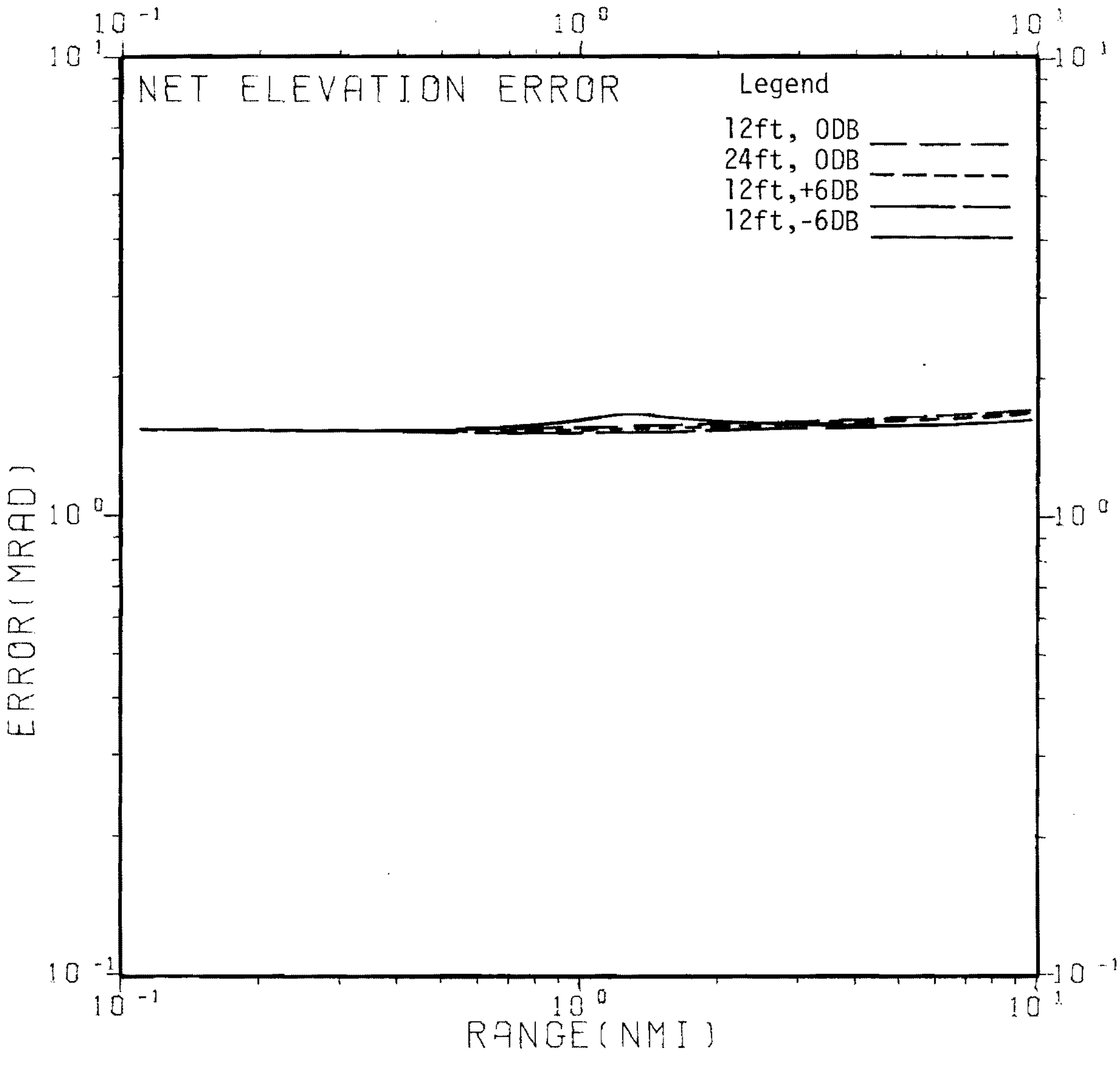

Figure 6-12. Net Elevation Tracking Error as a Function of Scatterer Separation and Relative Scatterer Strength.

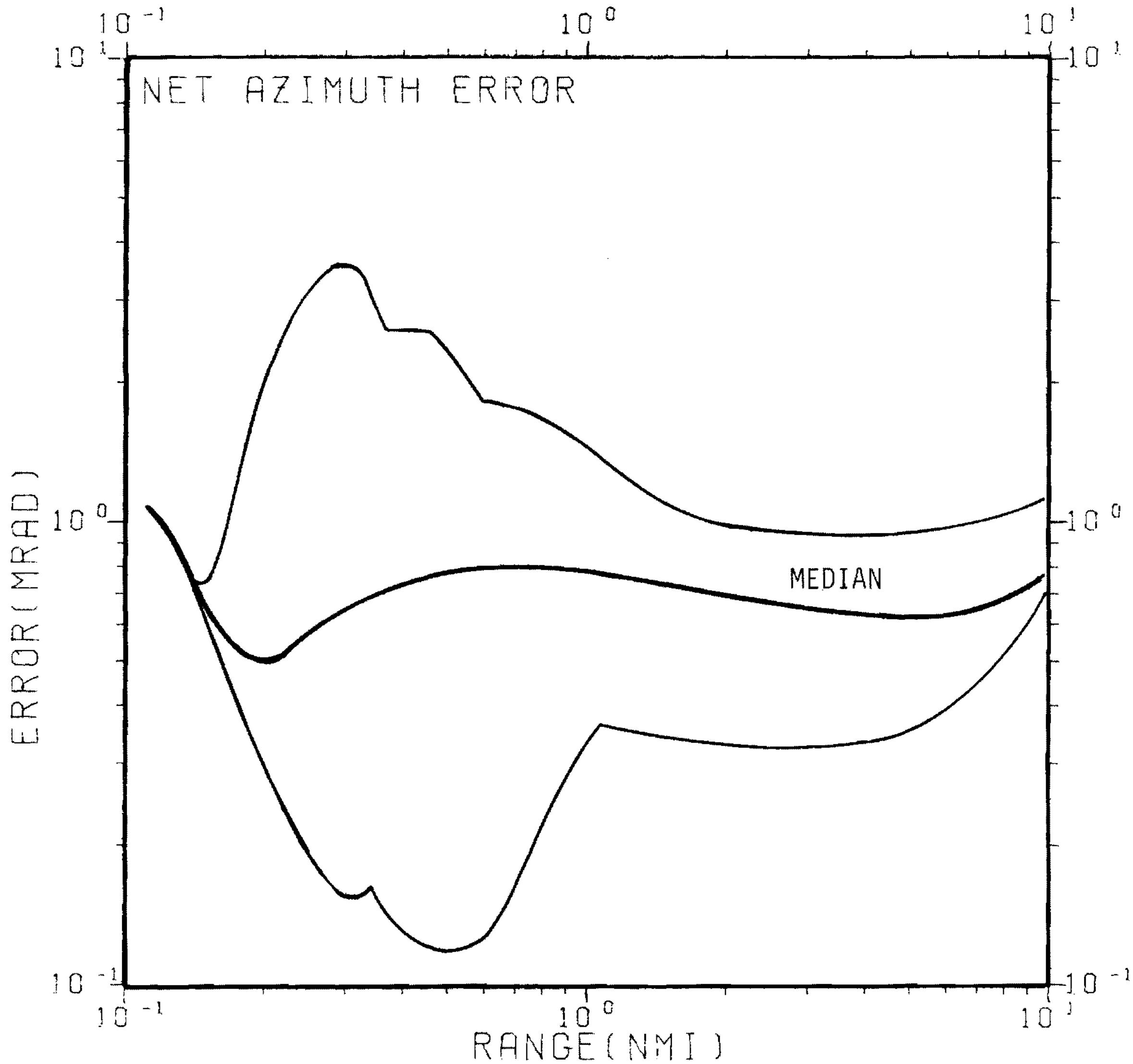

Figure 6-13. Limits of Net Azimuth Tracking Error Variation.

baseline case was found to be approximately two meters at all ranges. This performance should be adequate for the MATCALS mission. The range tracking error will be reduced to a one meter sigma at all ranges for certain combinations of sampling rate and track filter bandwidth, as is discussed in Section 7. Because the range tracking accuracy appears to be good enough and is not overly sensitive to changes in the radar system parameters, it will not be discussed further.

SECTION 7

PROBLEM AREAS IN THE MATCALS PRECISION APPROACH RADAR

7.1 General Methods of Reducing Tracking Errors

Integration of several position determinations on the same aircraft, each with uncorrelated errors, will yield a better estimate of the actual position than any single measurement. Better, in this context, means that the variance of the estimate of the actual position is less. For the AN/TPN-22 Precision Approach Radar (PAR), each position determination will have independent error components, so that integrating several position updates will yield better results. This integration, or averaging, may be accomplished in one of two ways: (1) decrease the track filter bandwidth to obtain more samples within the filter integration time, or (2) increase the position determination, or update, rate to greater than 10 Hz.

Figures 7-1 through 7-4 illustrate the effect of a reduced track filter bandwidth on the net azimuth and elevation accuracies. Note that the tracking errors are reduced at long ranges for both the 3.5 Hz and 1.0 Hz filter bandwidths, but that at close ranges the azimuth errors are increased tremendously and the elevation errors somewhat less. (The relative effect on the elevation accuracy is less because of the dominant frequency scintillation term.) This increase is due entirely to the tracking filter not responding fast enough to the pseudo-accelerations of the aircraft. Consequently, the filtered output lags the actual position. The term "pseudo-accelerations" is most important here. The aircraft is actually flying along a straight line at constant velocity and is not physically accelerating. But, if the tracking coordinate system is centered at the radar, as was assumed here, then the target appears to accelerate; hence the term pseudo-accelerations. Both of the above bandwidths, 3.5 and 1.0 Hz, appear to produce unacceptably large angular tracking errors when compared to the baseline 6.67 Hz situation. In fact, the baseline track filter error appears to be near optimum overall.

Since the filter lag is due to the location of the origin of the coordinate system, it is logical that shifting the origin to a point where the accelerations are zero should reduce the error. This is indeed the case, as in shown in Figures 7-5 and 7-6 for a 6.67 Hz bandwidth and Figures 7-7 and 7-8 for the 3.5 Hz bandwidth, in these figures, the origin has been shifted to the touchdown point. In both cases, the

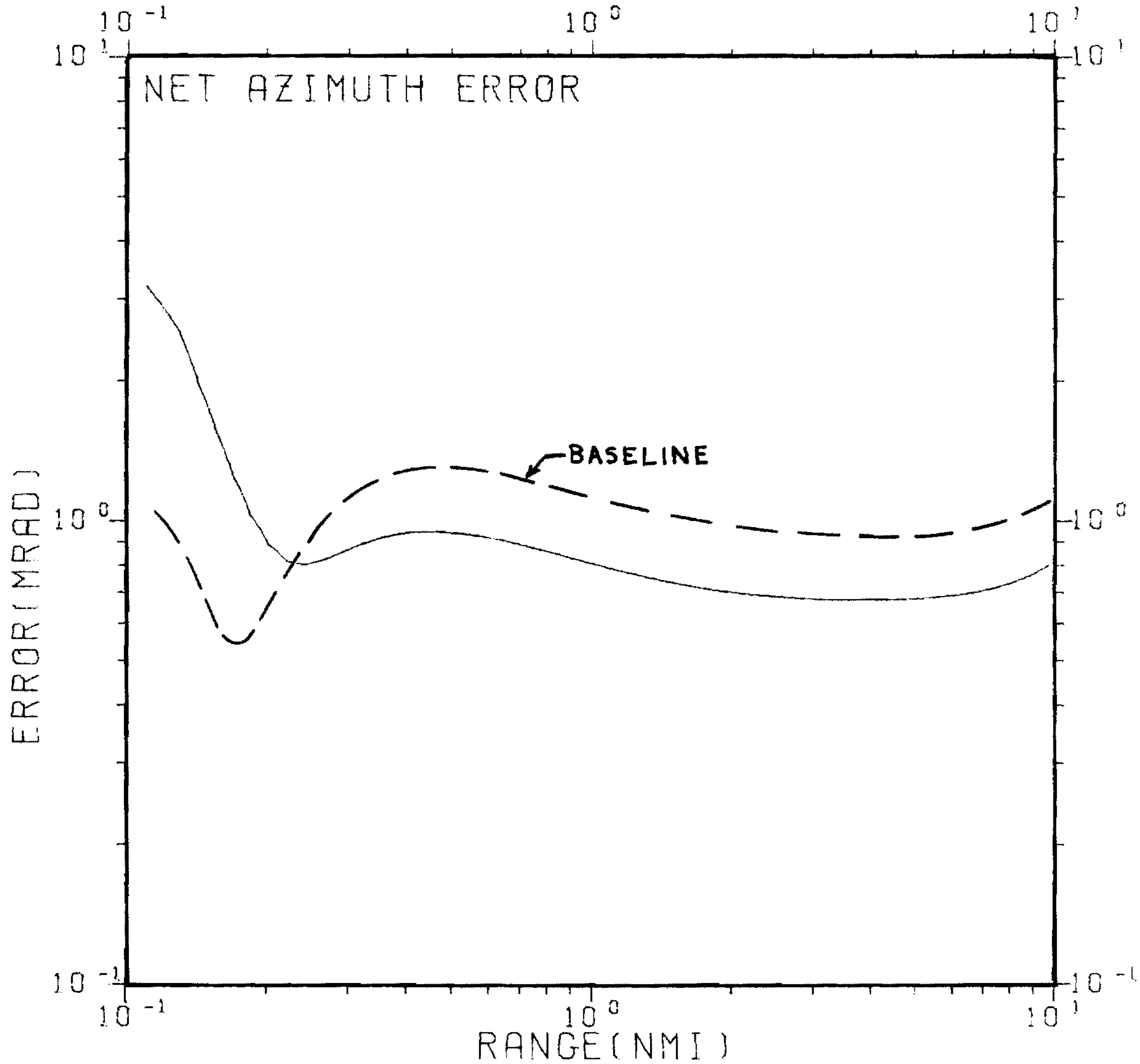

Figure 7-1. Net Azimuth Tracking Error for a 3.5 Hz Filter Bandwidth.

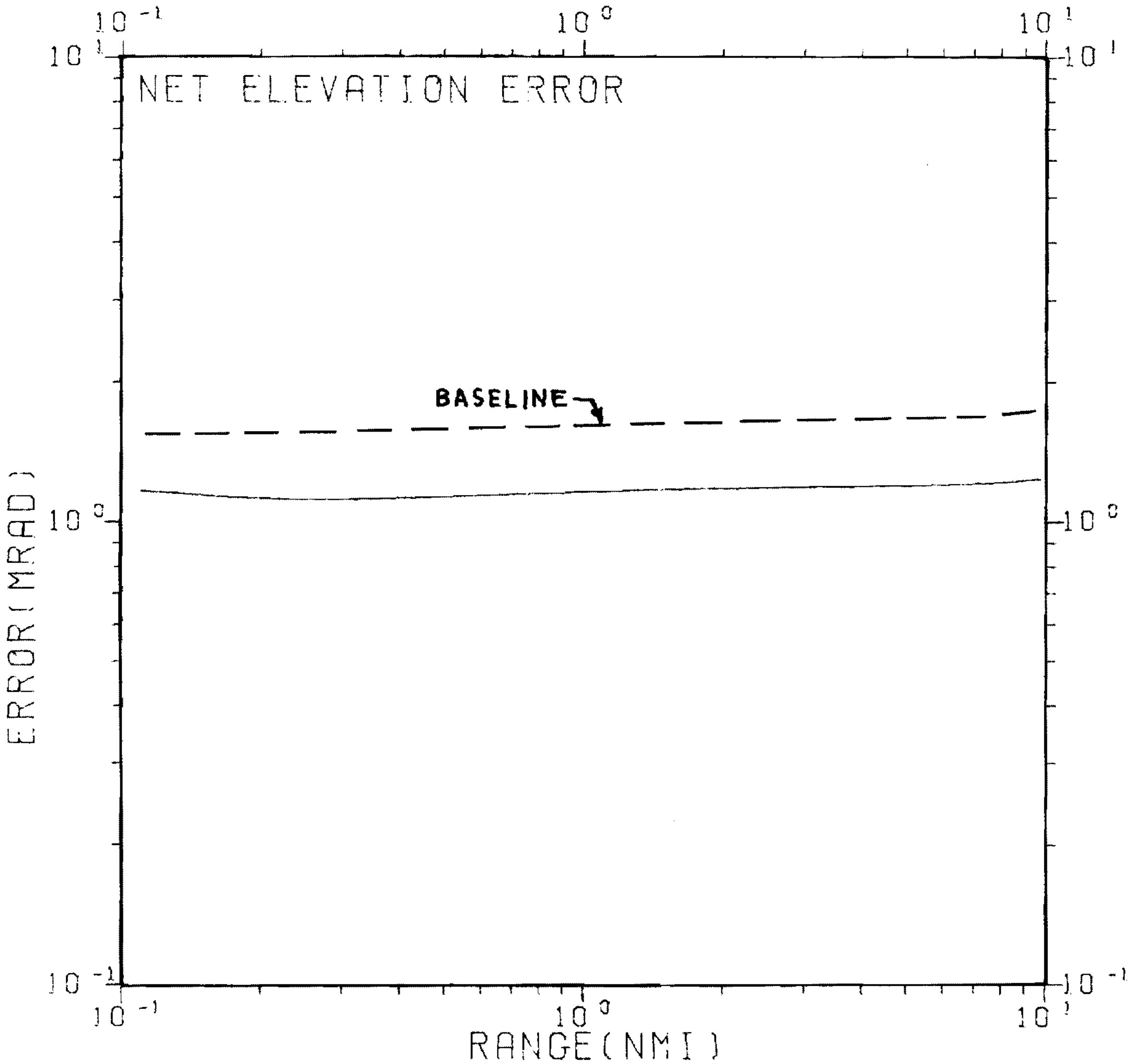

Figure 7-2. Net Elevation Tracking Error for a 3.5 Hz Filter Bandwidth.

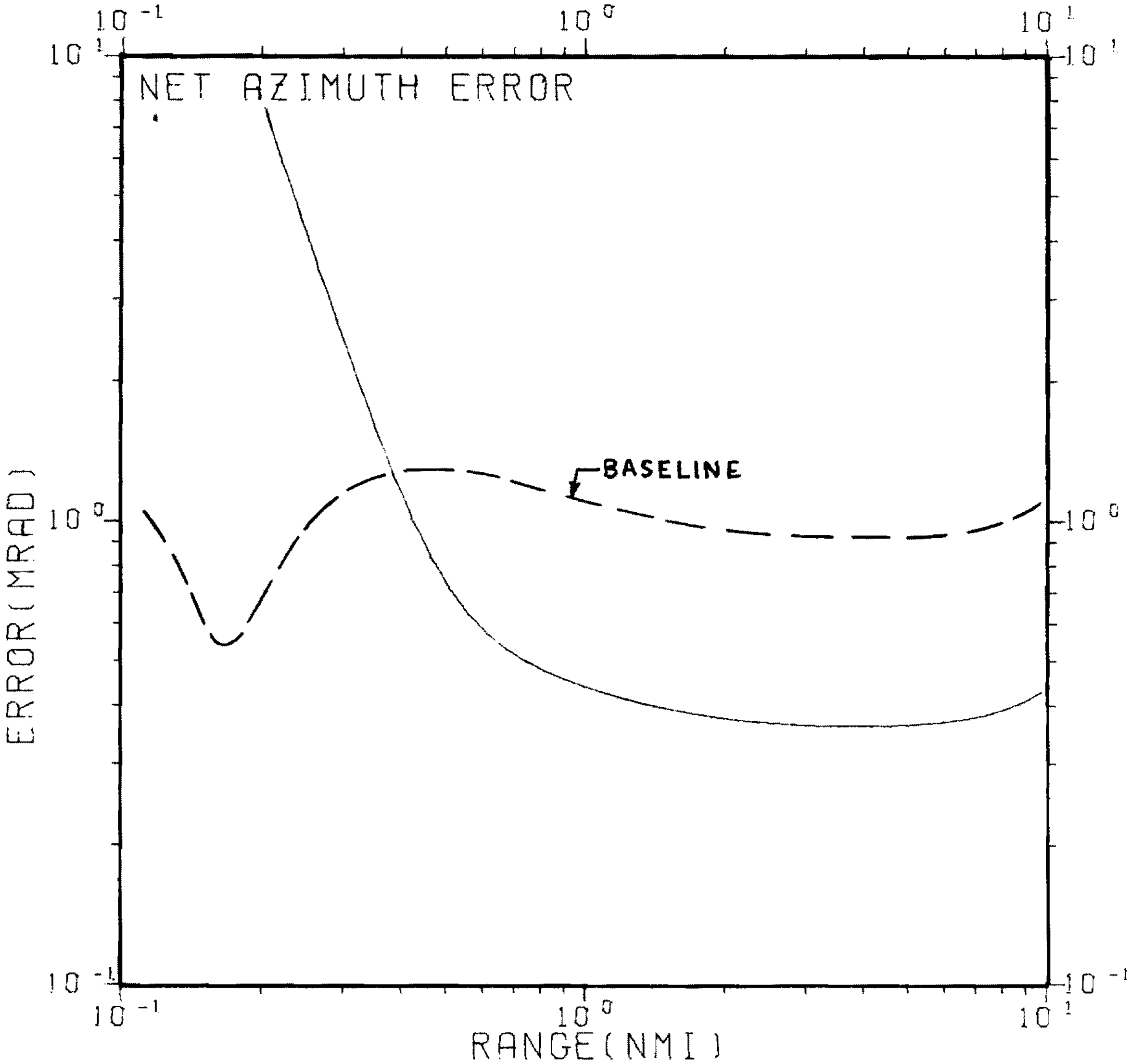

Figure 7-3. Net Azimuth Tracking Error for a 1.0 Hz Filter Bandwidth.

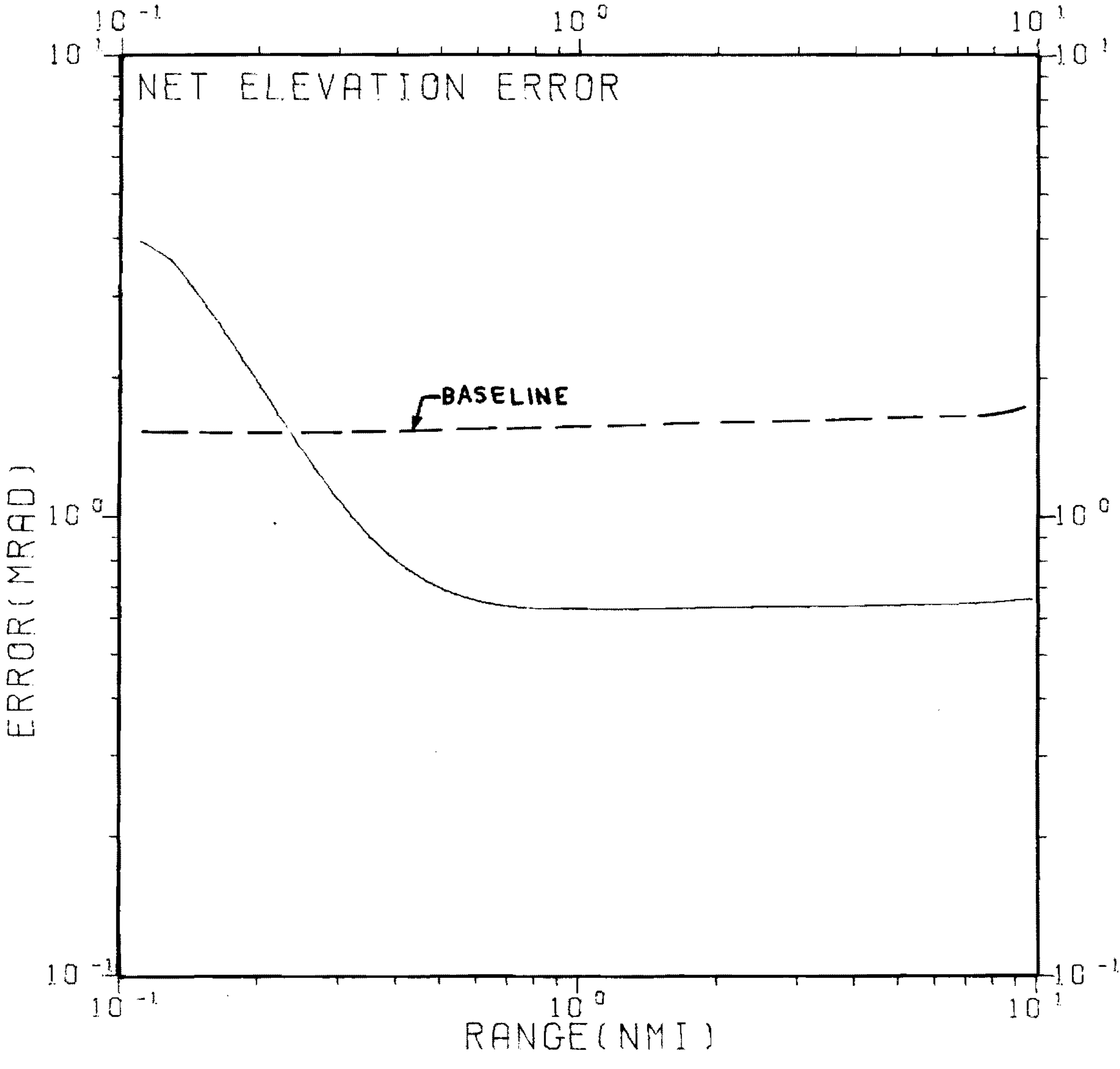

Figure 7-4. Net Elevation Tracking Error for a 1.0 Hz Filter Bandwidth.

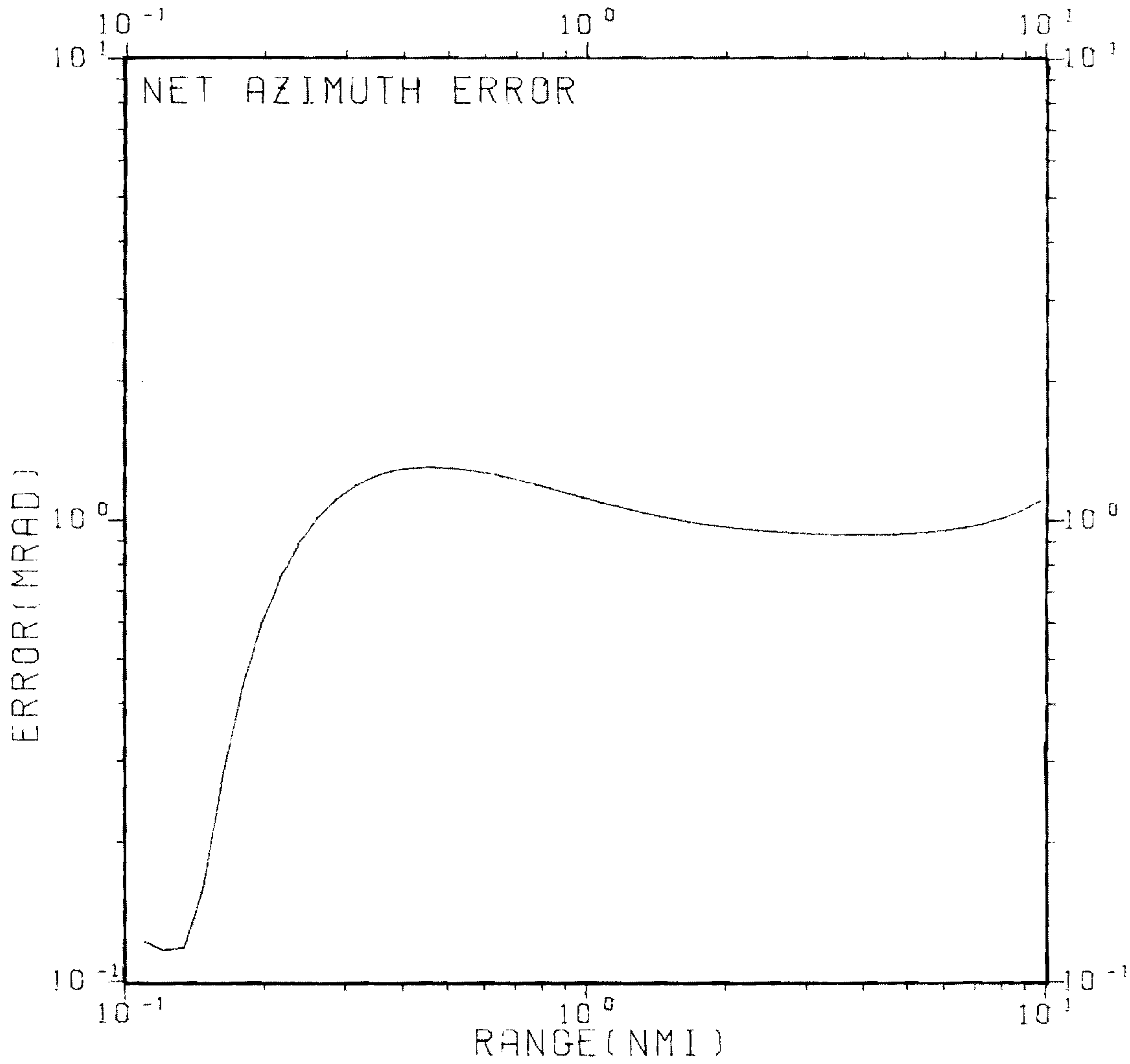

Figure 7-5. Net Azimuth Tracking Error With Origin Shifted to Touchdown Point and a 6.7 Hz Filter Bandwidth.

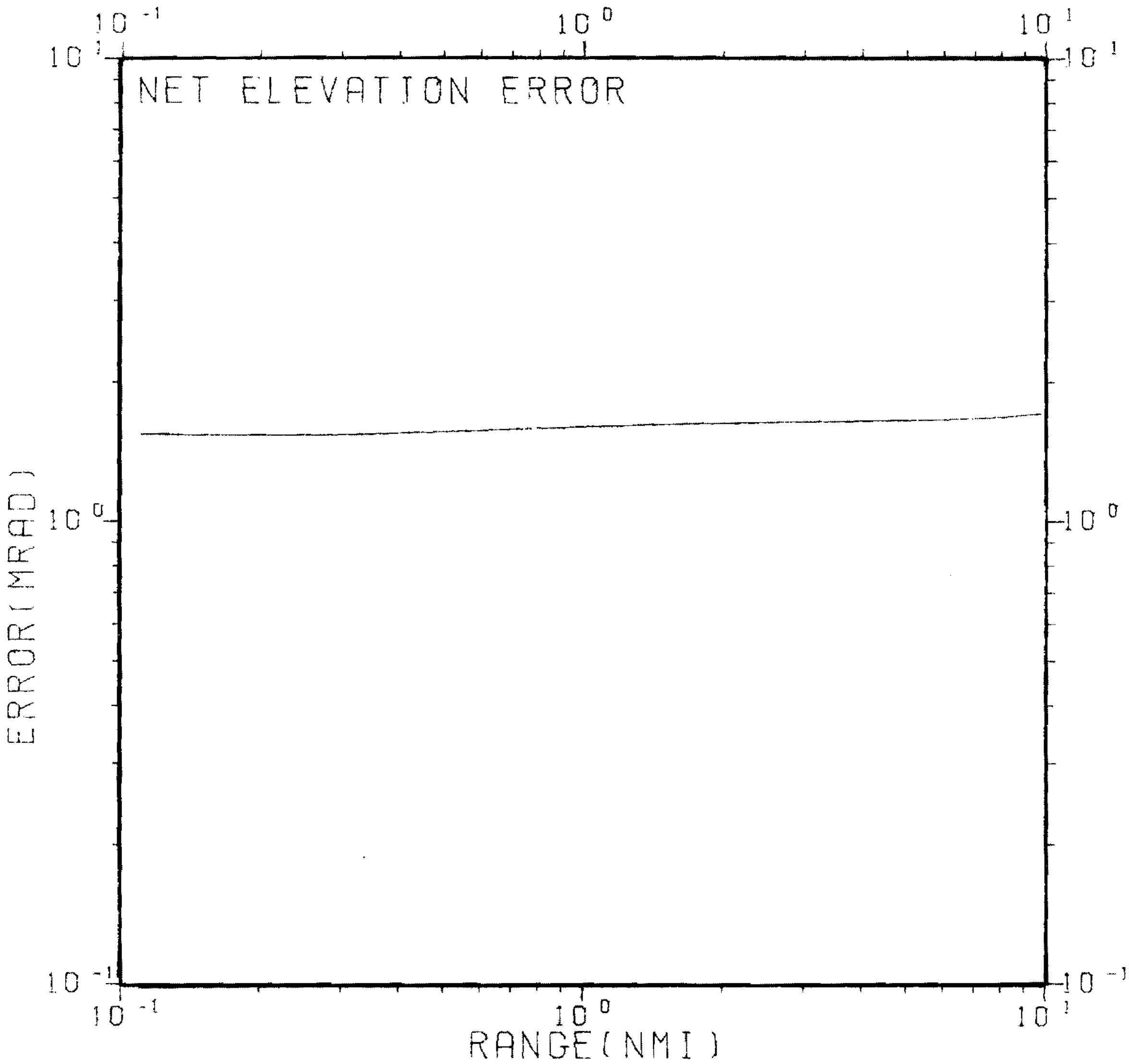

Figure 7-6. Net Elevation Tracking Error With Origin Shifted to Touchdown Point and a 6.7 Hz Filter Bandwidth.

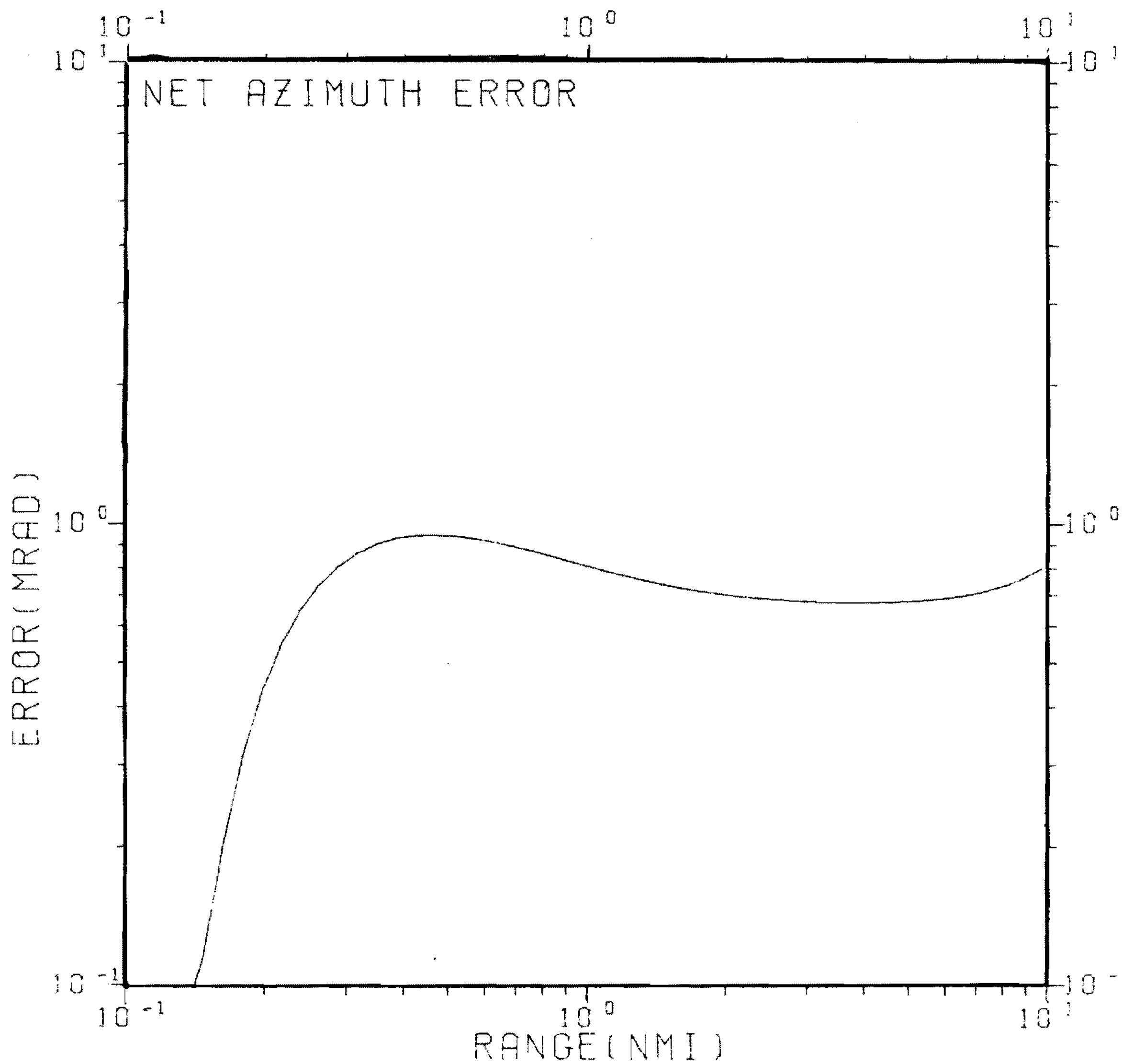

Figure 7-7. Net Azimuth Tracking Error with Origin Shifted to Touchdown Point and a 3.5 Hz Filter Bandwidth.

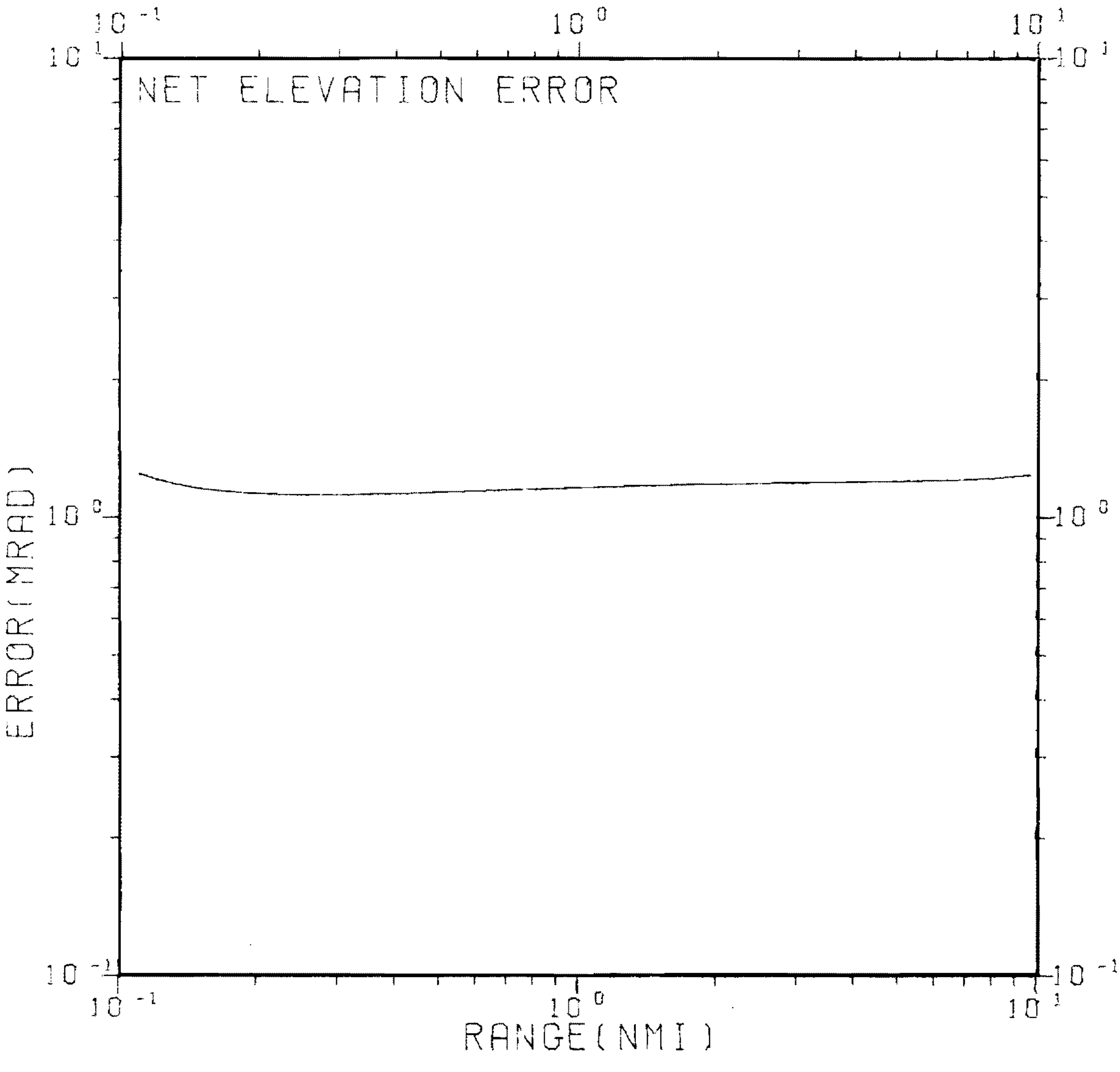

Figure 7-8. Net Elevation Tracking Error with Origin Shifted to Touchdown Point and a 3.5 Hz Filter Bandwidth.

filter lag term is reduced to zero, and there is noticeable improvement at ranges of less than 0.3 mile.

Movement of the origin of the coordinate system to the touchdown point should be effected if it has not already been accomplished. A corresponding reduction of the filter bandwidth must be approached with caution, however, because the filter lag applies not only to pseudo-accelerations, but equally to real accelerations. Thus, if a wind gust, for example, causes the aircraft to move off the desired glidepath, a narrow bandwidth filter could cause an unacceptably long delay in initiating a corrective maneuver.

The optimum tracking filter adapts its characteristics to the conditions it encounters. This is the theory behind Kalman filtering and adaptive α/β filtering. In the MATCALS application, where most of the targets follow a similar flight path, the complexity of an adaptive filter may not be required, although an adaptive scheme would be the best for dealing with variable winds and differing landing patterns. A possible alternative to an adaptive filter is one with a bandwidth which varies as a function of range in a predetermined manner. Figure 7-9 shows how the 6.67, 3.5, and 1.0 Hz filters could be used to yield better azimuth performance than any single fixed bandwidth filter. The heavy line indicates the tracking error associated with this situation which at any range is the best of the three. Note that the filter bandwidth changes at ranges of .22 mile and .43 mile. Significant improvement will be obtained with either this approach or an adaptive filtering technique.

The second method for integrating more samples is to increase the position update, or sampling, rate, while keeping the filter bandwidth constant. Figures 7-10 through 7-13 illustrate how a 20 Hz and 30 Hz sampling rate affect the net azimuth and elevation tracking errors. (The servo bandwidth is 6.67 Hz, as in the baseline.) The baseline 10 Hz errors are shown as a dotted line in each figure for reference. Note that the errors are reduced at all but close ranges. This is again due to the dominating servo lag effect. Changing the sampling rate will not affect the servo lag because these error samples are not uncorrelated and, hence, the average error will not be reduced. In order for track filter errors to be uncorrelated, they must be separated in time by approximately the reciprocal of the bandwidth, or in this case, 1/6.67 = 0.15 seconds. Similarly, if the errors due to other sources are correlated from update to update, integration of more samples will not reduce the error. This

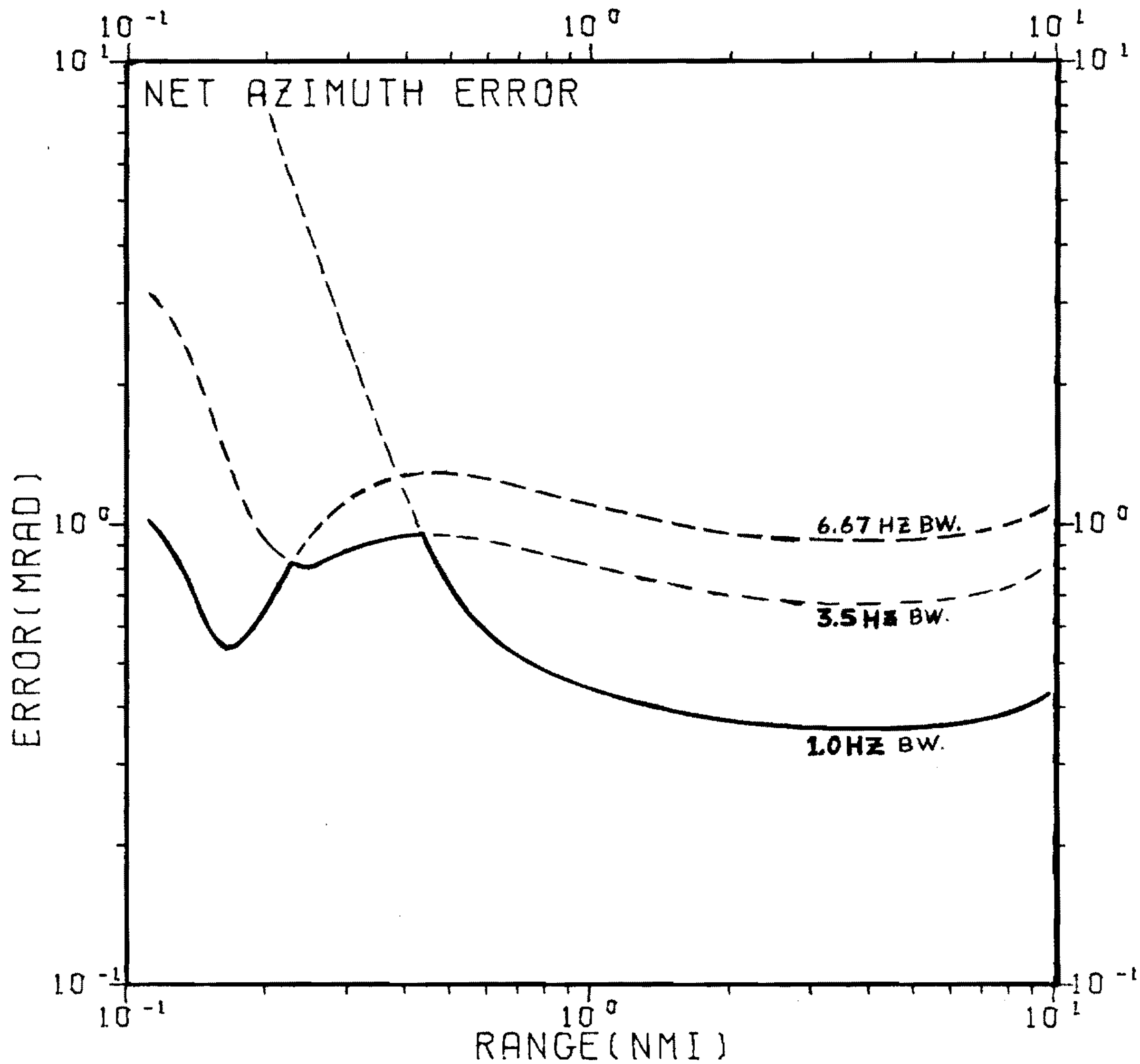

Figure 7-9. Net Azimuth Tracking Error Using Three Fixed Bandwidth Filters to Improve Performance.

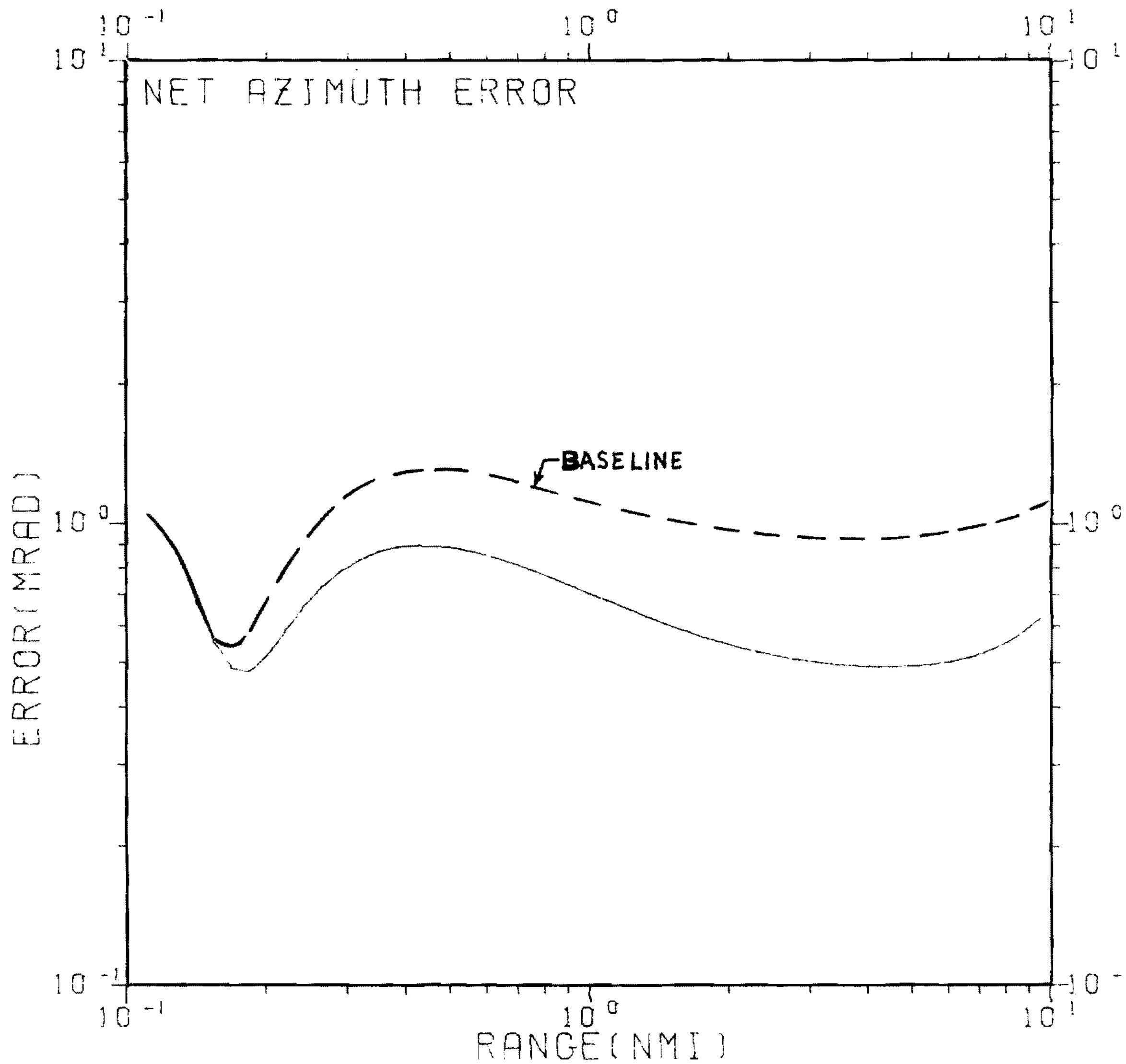

Figure 7-10. Net Azimuth Tracking Errors with a 20 Hz Sampling Rate.

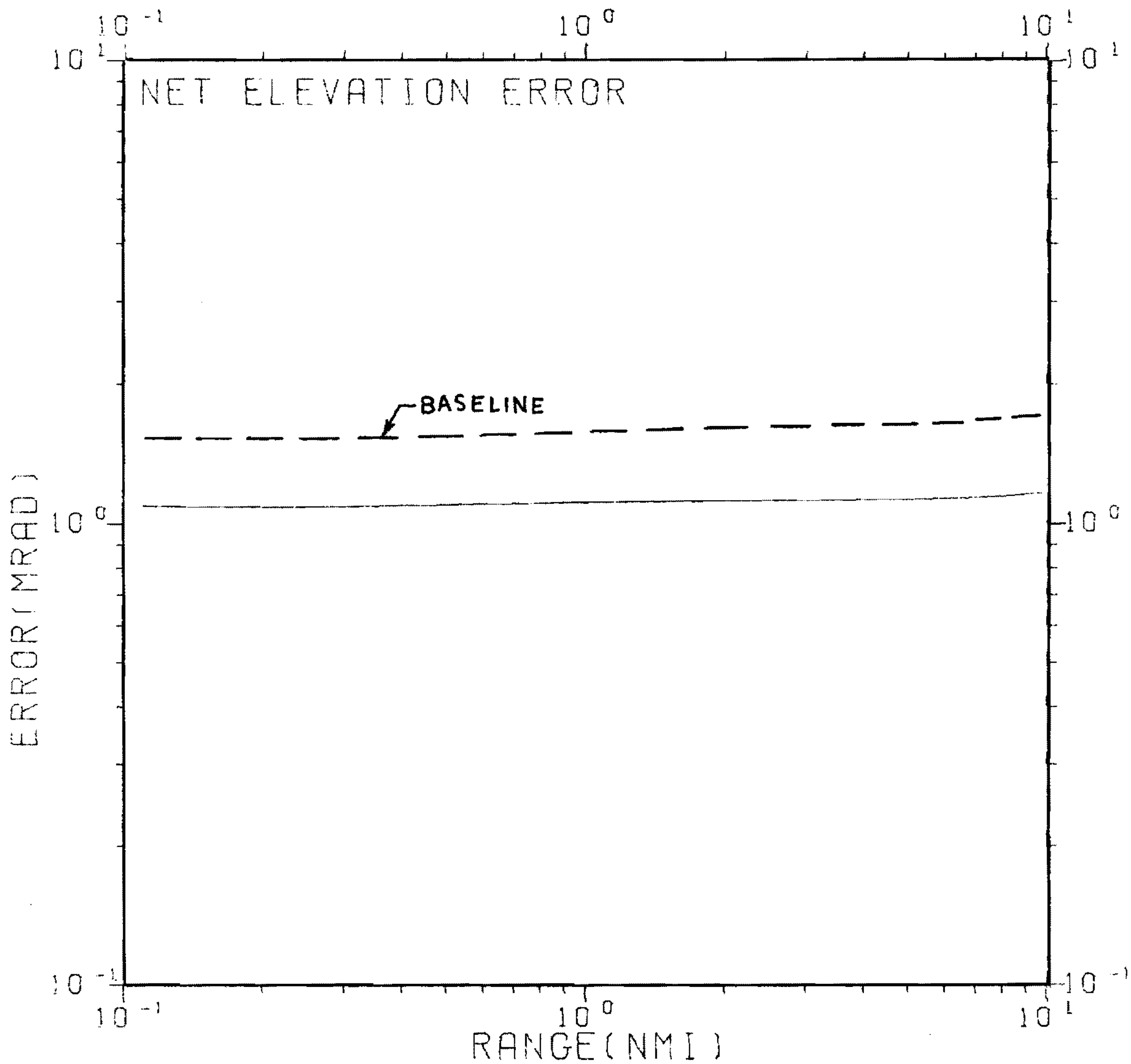

Figure 7-11. Net Elevation Tracking Error with a 20 Hz Sampling Rate.

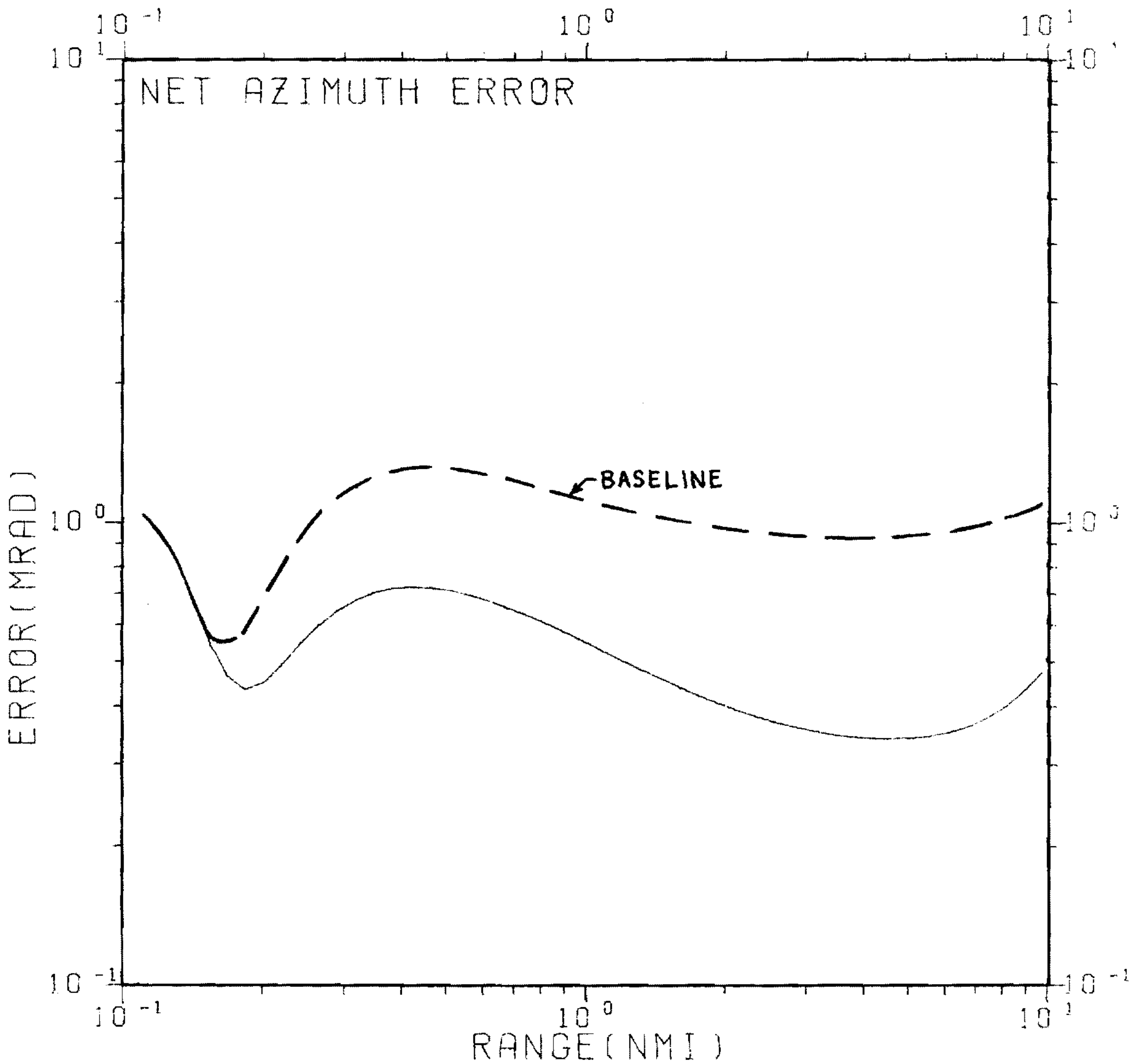

Figure 7-12. Net Azimuth Tracking Errors With a 30 Hz Sampling Rate.

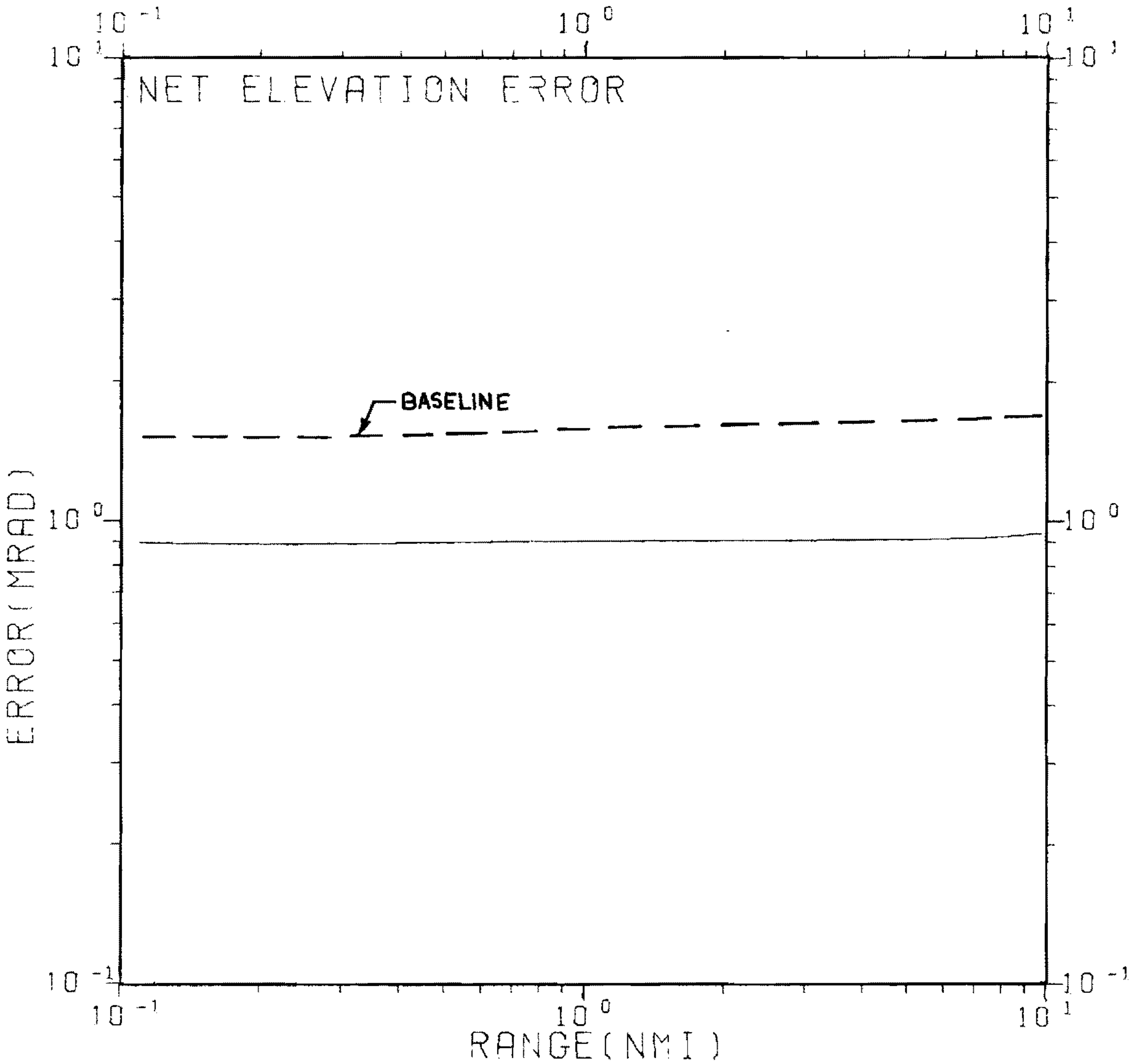

Figure 7-13. Net Elevation Tracking Error With a 30 Hz Sampling Rate.

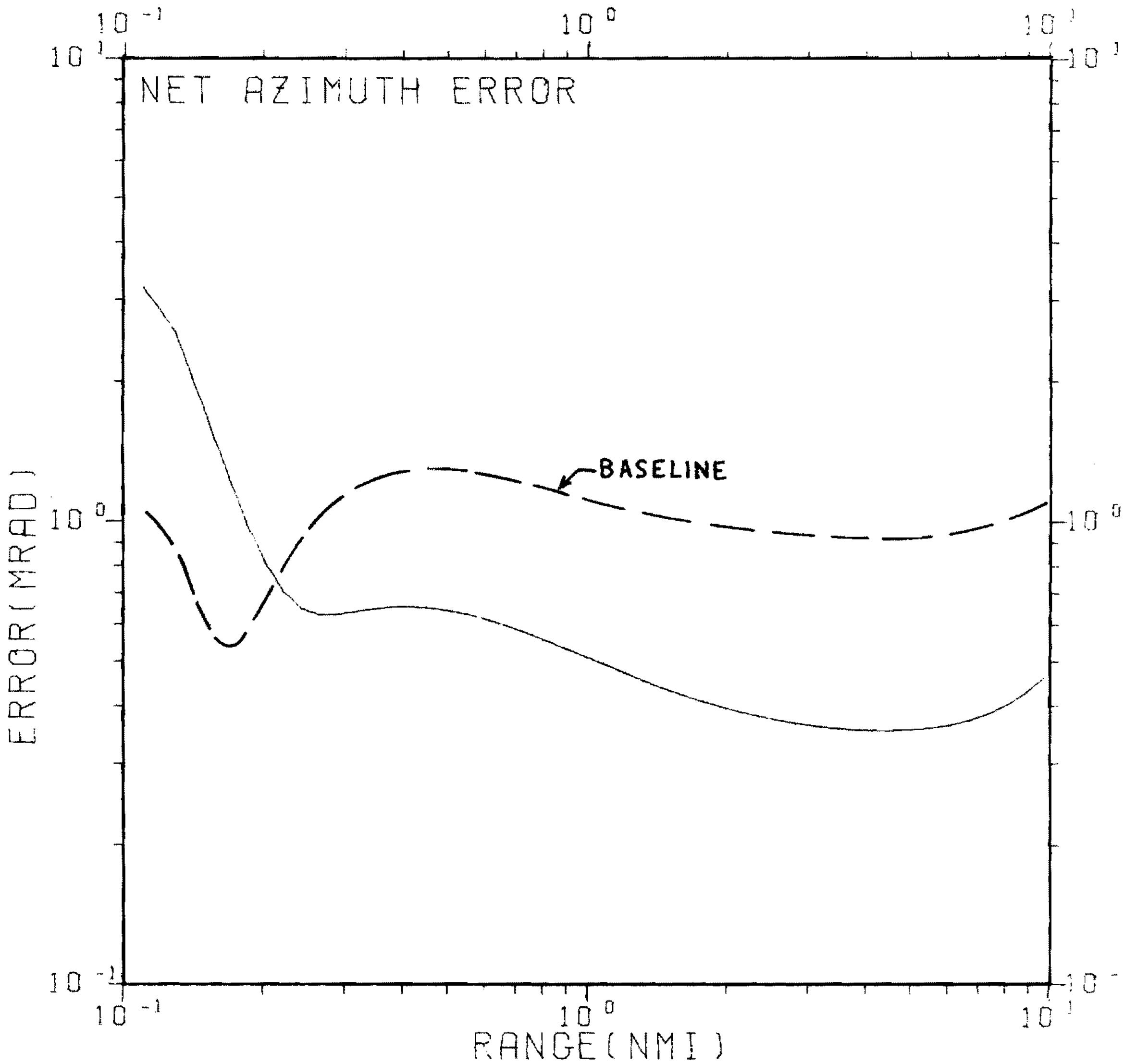

Figure 7-14. Net Azimuth Tracking Errors With a 20 Hz Sampling Rate and a 3.5 Hz Filter Bandwidth.

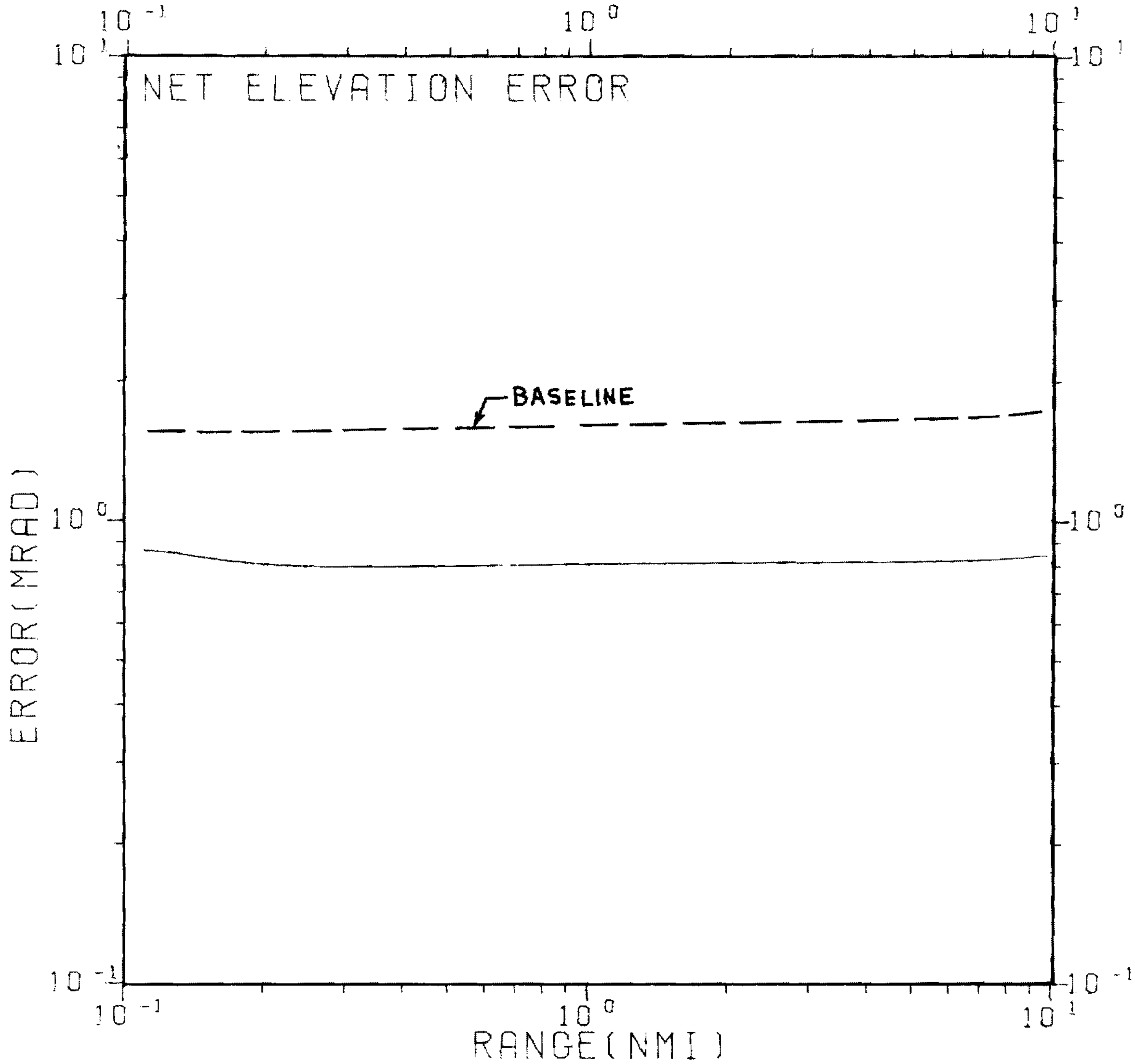

Figure 7-15. Net Elevation Tracking Error With a 20 Hz Sampling Rate and a 3.5 Hz Filter Bandwidth.

would be the case, for example, if the radar scattering centroid of the aircraft slowly moves in relation to the geometrical aircraft centroid.

Different combinations of sampling rates and track filter bandwidths will yield different, but related, results. Refer to Figures 7-10 and 7-11 and to Figures 7-14 and 7-15 where the sampling rate is 20 Hz and the track filter bandwidths are 6.67 and 3.5 Hz, respectively. The important point to note is that the results at ranges greater than where servo effects dominate (about 0.3 mile) are mostly determined by the square root of the ratio of the sampling rate over the track filter bandwidth. Thus Figures 7-10 and 7-11 resemble Figures 7-1 and 7-2, the 10 Hz update rate with a 3.5 Hz bandwidth, and Figures 7-14 and 7-15 resemble the 1.0 Hz cases, Figures 7-3 and 7-4. Increasing the sampling rate while retaining a constant track filter bandwidth has the important advantage over just reducing the bandwidth of not increasing the track filter lag over the baseline case. This is especially valuable in the MATCALS application, since accuracy at close range is very important.

One reason for choosing the 10 Hz sampling rate for MATCALS is that 10 Hz is the maximum update rate that allows tracking six targets simultaneously. It might be advantageous to employ different sampling rates as a function of range in order to minimize the overall error. One such scheme, which has not been optimized at all, but is presented only for discussion, would be to use a 30 Hz update rate for a target between the Freeze Command Point and 1.5 miles range, a 10 Hz sample rate for targets between ranges of 1.5 and 3.0 miles, and a 5 Hz update rate for targets at ranges beyond 2.5 miles. Assuming there are six aircraft in the approach pattern and they are uniformly spaced over ten miles, then there will be one aircraft being tracked at a 30 Hz rate, one at a 10 Hz rate, and four at a 5 Hz rate. The total number of updates per second will be 60, which is the same as sampling six aircraft at a 10 Hz rate. Thus the tracking computer workload will be about the same. Figure 7-16 shows the corresponding azimuth errors, and Figure 7-17 illustrates the elevation errors, for tracking filter bandwidths of 6.67 Hz in the near range region and 1.0 Hz in the other two regions. The baseline case is also shown for comparison.

Another side benefit could result from changing the sampling rate as a function of range. The digital track filter algorithms would be designed for a 5 Hz sample rate and a 1.0 Hz bandwidth. This design assigns values to the feedback parameters, the feed forward parameters, and constants. Then, if the sampling rate

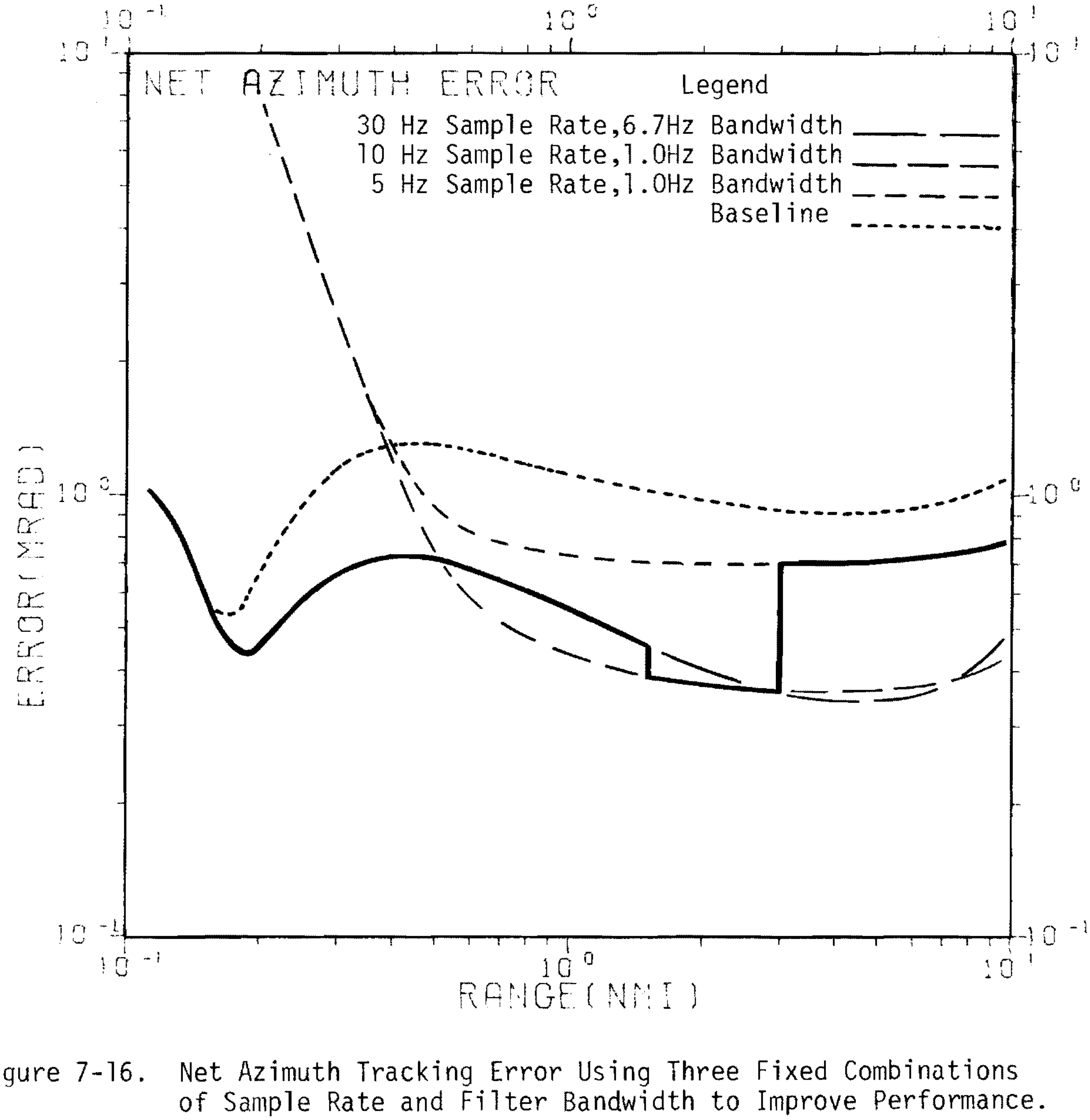

Figure 7-16. Net Azimuth Tracking Error Using Three Fixed Combinations of Sample Rate and Filter Bandwidth to Improve Performance.

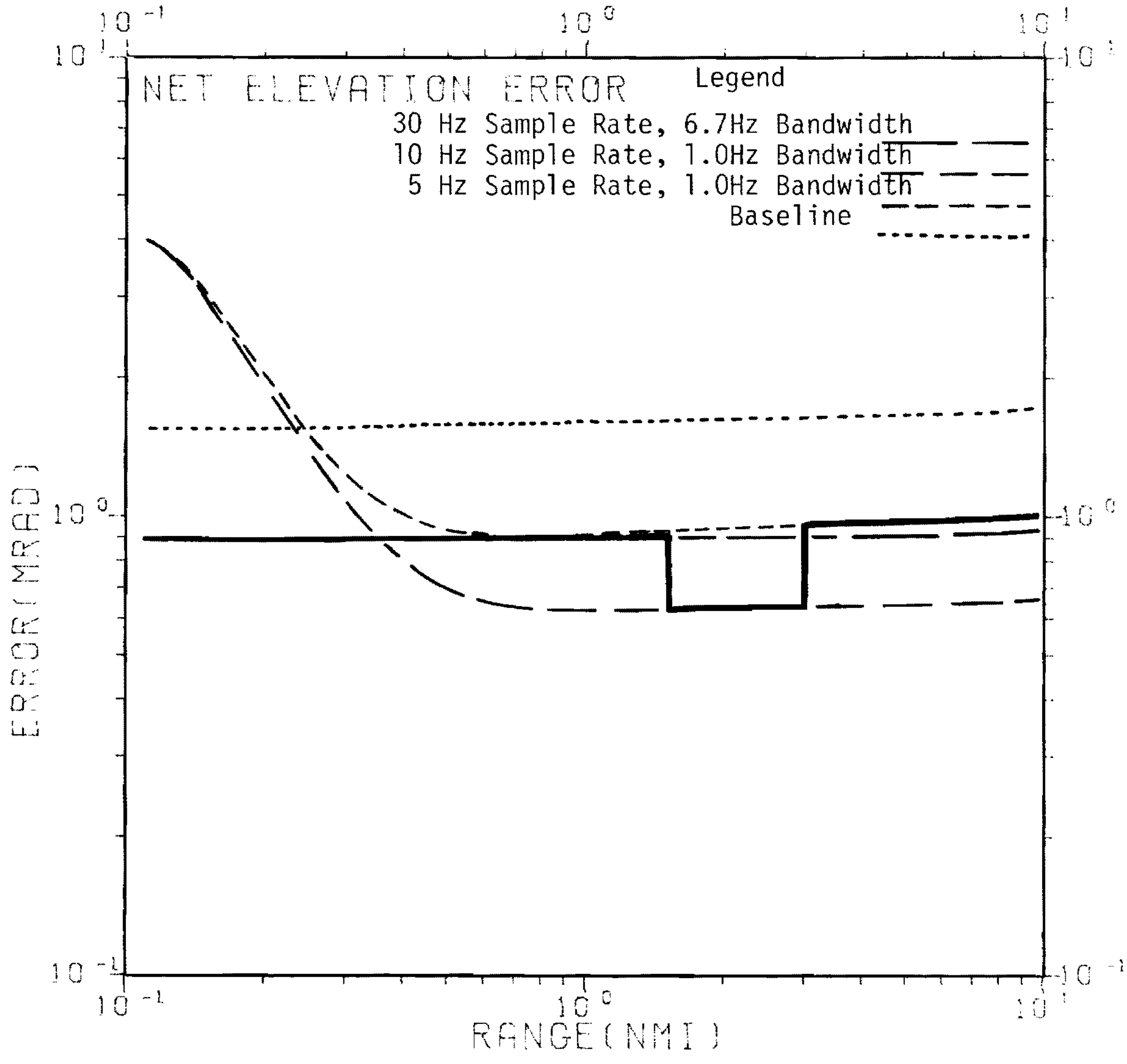

Figure 7-17. Net Elevation Tracking Error Using Three Fixed Combinations of Sample Rate and Filter Bandwidth to Improve Performance.

changes by a factor K, the bandwidth is changed by the same factor of K. This may be seen intuitively by thinking of the filter as taking a certain number of samples, say N, to respond to a step input. With a time between samples of T, the response time will be NT. If the sampling rate is increased by a factor of K, then the time between samples will be reduced to T/K. Thus, for identical filter parameters, the filter's response time will be given by NT/K. Then, since the bandwidth is inversely proportional to the response time, one observes that the bandwidth has been increased by the factor K. In the modified MATCALS example above, the filter parameters were designed for a 5 Hz sample rate and 1.0 Hz bandwidth. In the range of 3.0 to 1.5 miles the sampling rate is increased to 10 Hz with a corresponding rise in filter bandwidth to 2.0 Hz. From 1.5 miles into touchdown, a 30 Hz sample rate yields a filter bandwidth of 6.0 Hz. The above approach must be examined for its effects on the closed loop stability of the landing system, but an approach such as this will work and could yield savings in computer execution time.

7.2 Specific Tracking Accuracy Improvement

The techniques mentioned above will help to reduce tracking errors both in elevation and azimuth. Statistical reduction of errors by these techniques are limited in their usefulness, however, due to the decreasing rate of return indicated by the $\sqrt{N}$ type of expected improvement. Obtaining a large improvement requires some basic change in the tracking technique or processing.

7.2.1 Elevation Tracking

Elevation tracking accuracy has been shown to be limited by the induced scintillation due to the frequency agility used to scan the beam vertically. Any methods of improving the elevation tracking accuracy must address this problem in order to be successful. Unfortunately, there is very little that can be done to get around this phenomena without major changes to the AN/TPN-22 radar system, which are unacceptable. As was mentioned before, the theory behind the analysis technique used to determine the frequency scintillation error is valid and based on measured data. However, in order to verify the errors which the MATCALS system is actually experiencing, a measurement program would have to be undertaken. After reducing the measured data, the actual effect of the induced scintillation would be known, as would other effects. At that point, and only then, can a viable plan be formulated for reduction of elevation tracking errors.

7.2.2 Azimuth Tracking

Unlike the elevation accuracy, sources of the limiting tracking errors in azimuth change as a function of range. As can be seen in Figure 6-2, track filter lag limits performance at very short ranges; glint and scintillation are the limiting factors at short and medium range; and scintillation and signal-to-noise ratio limit the long range accuracy. It was shown earlier that the track filter errors could be reduced to negligible values by shift of the origin of the tracking computation coordinate system to the expected touchdown point. The long and medium range azimuth accuracies could be improved by suitable choice of the tracking filter characteristics, but are already adequate in this range region. Thus, the region which requires improved performance is from 0.2 to 2.0 miles in range. Any method which would increase the probability of edge track would yield the greatest benefits in this region.

One such technique, alluded to in Section 6, is to shape the antenna pattern to increase the probability of edge. As illustrated in Figure 7-18, this consists of sharpening, or increasing the slope of the beam, on the forward edge of the beam at the expense of the trailing edge.

The effect of such a change on the net azimuth errors for the baseline case may be approximated by specifying a scatterer separation of 12 feet instead of the normal 6 feet. Computationally, doing this is about the same as doubling the slope of the two-way power antenna pattern. The results are shown in Figure 7-19, with the baseline errors shown for comparison. Tracking accuracy is seen to be markedly improved in the region of interest. Figure 7-20 plots the probability of edge for these two cases. Note that a 50% probability of edge track is attained at double the range for the increased slope beam.

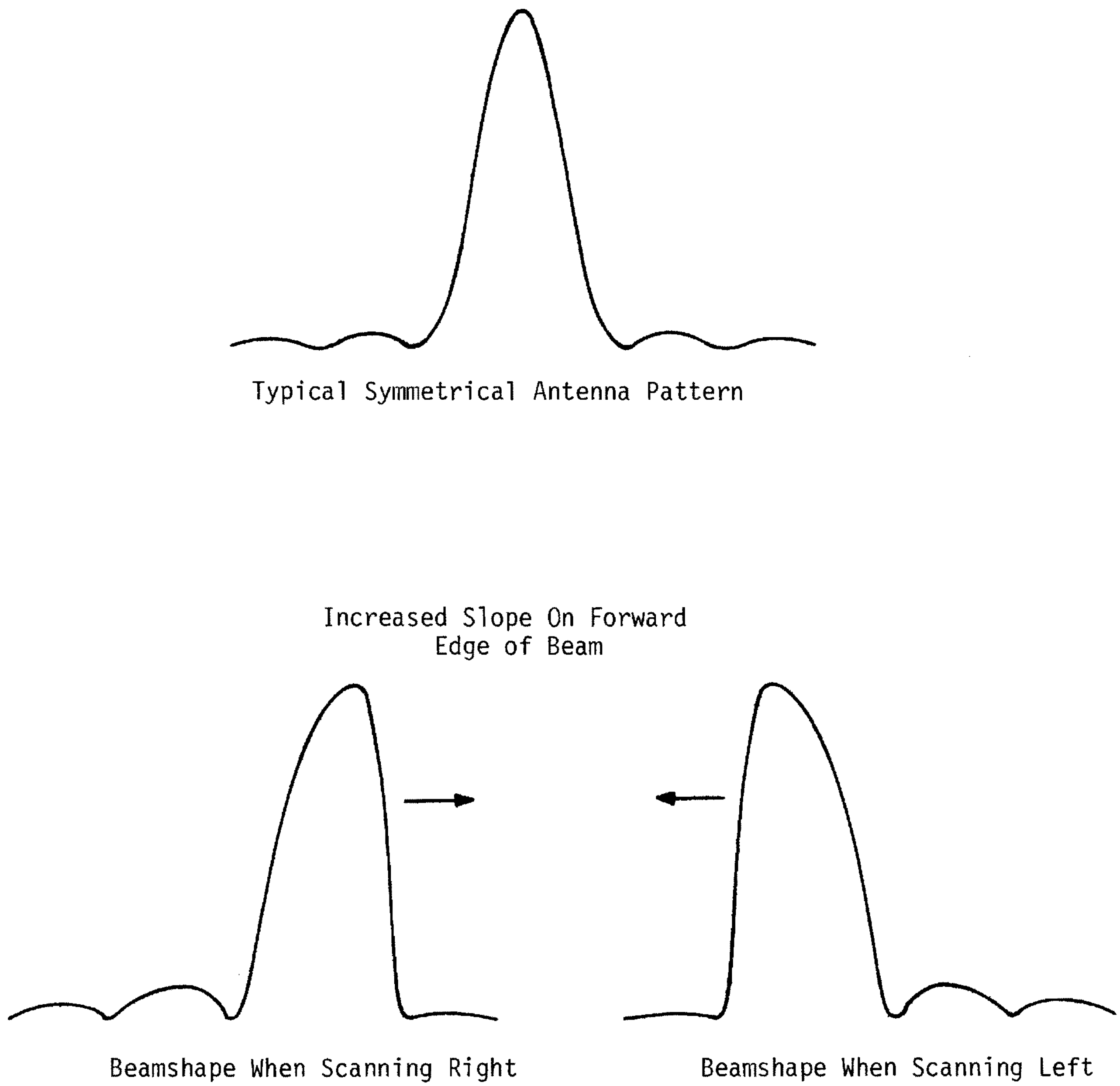

Figure 7-18. Beamshaping To Improve Edge Track Performance.

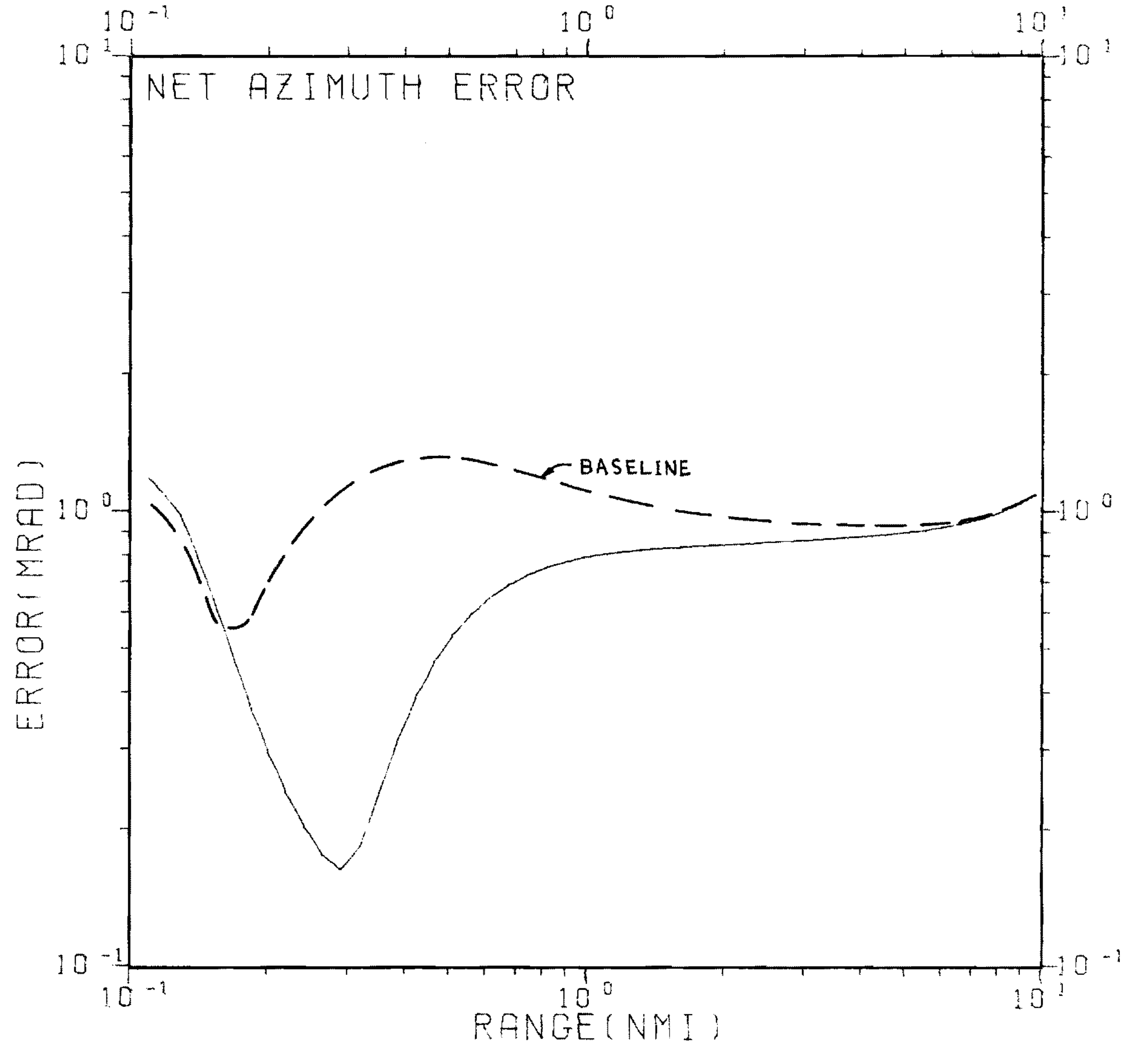

Figure 7-19. Approximate Net Azimuth Tracking Error for Increased Slope Beam.

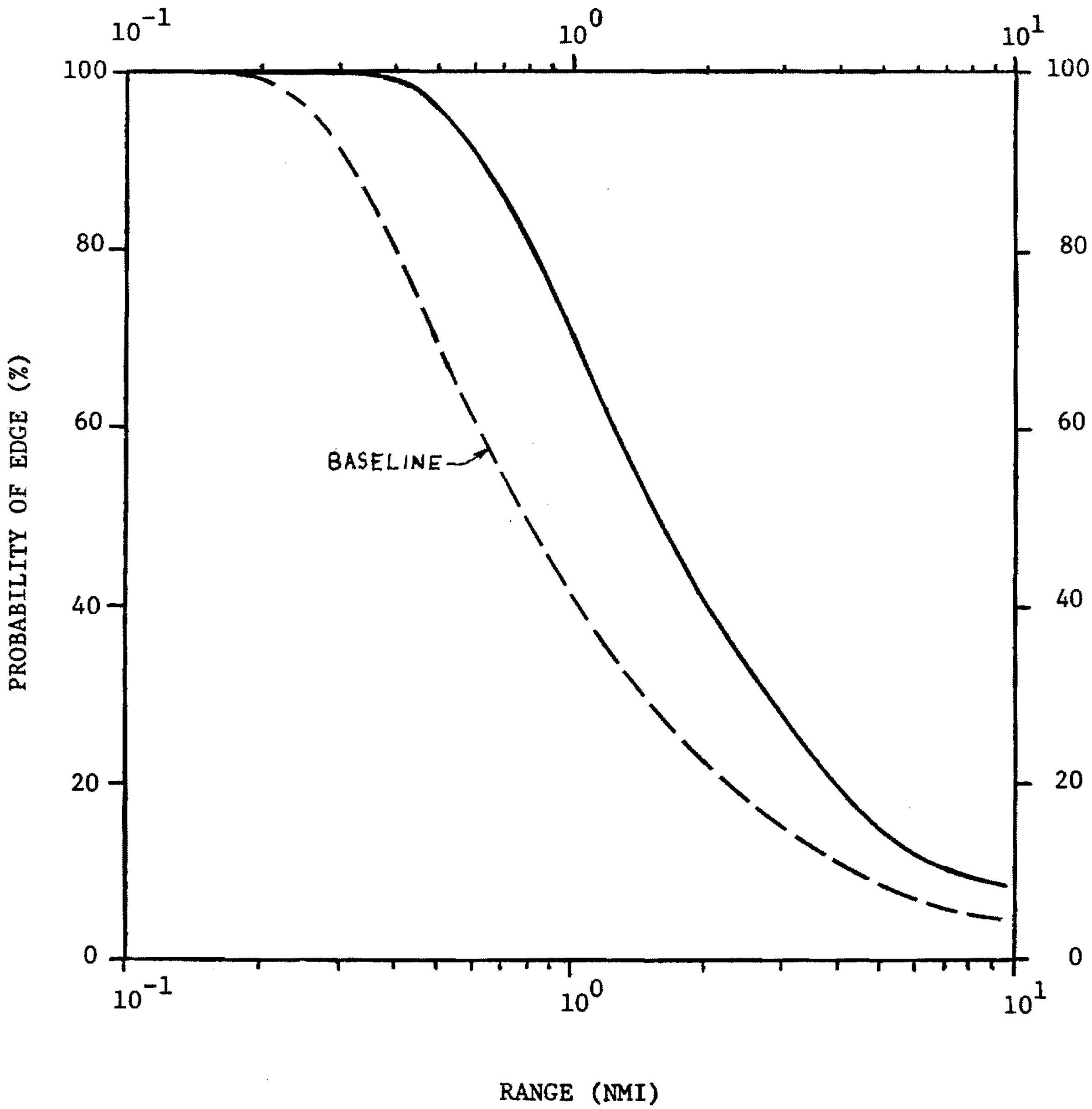

Figure 7-20. Probability of Edge Track Versus Range For Increased Slope Beam.

SECTION 8
CONCLUSIONS AND RECOMMENDATIONS

The AN/TPN-22 radar system employing the edge track technique appears to be a feasible Precision Approach Radar (PAR) for the MATCALS application. A more definite statement to that effect is not warranted, due to the difficulty in defining performance requirements for the PAR system. Analysis indicates that this PAR yields better performance at close ranges than at long ranges, which is desirable in this application. Specific conclusions are listed below:

a. The AN/TPN-22 signal-to-noise ratio is sufficient and very well matched to the MATCALS PAR application.

b. Instrumental/Granularity errors are negligble.

c. Tracking filter analysis indicates that the center of the tracking coordinate system must be at the touchdown point. A variable filter bandwidth and variable update rate as a function of range may yield increased tracking accuracy over the entire range of the PAR.

d. Elevation tracking errors are dominated by induced scintillation due to frequency scanning in that dimension.

e. Scintillation and glint errors in the azimuth plane may be reduced by increasing the edge track probability.

f. Clutter and multipath errors should be small on a 3.5^{o} glideslope when the mainbeam does not intersect the ground or other large clutter patch.

g. The analysis results are very sensitive to certain assumptions and parameters. The choice of values for these parameters should be verified and updated as knowlege is gained.

Georgia Tech recommends that several tasks be immediately undertaken to validate the theoretical predictions and to improve the radar system's accuracy. Most of the recommended modifications to the radar system are minor and may be implemented solely in software. These recommendations are listed below:

a. Compare current measured data to theoretical predictions to validate and refine those predictions.

b. Update the computer analysis model using data obtained in a. above and include recent radar modifications installed by ITT-Gilfillan on the AN/TPN-22.

c. Explore tracking data optimization schemes. This includes tradeoffs of position update rates and tracking filter characteristics versus range in order to optimize performance for the MATCALS mission.

d. Determine the effect of recommended operational changes determined in c. above on the closed loop stability of MATCALS.

e. Investigate adaptive filtering schemes or filters which change parameters in a fixed manner as a function of range. This task must be performed in conjunction with c. above.

f. Define the required radar performance as a function of range. This task may be approached from an analytical or a measurement of actual performance standpoint.

g. From the results of task f. above, if the azimuth accuracy requires improvement, explore methods of implementing beam sharpening.

h. From the results of task f. above, if the elevation accuracy requires improvement, initiate a measurement program to determine the actual effects of induced frequency dependent target backscatter scintillation.

i. At the conclusion of the data analysis, determine the best approach to follow for improving the elevation tracking accuracy.

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